SURVEY OF NAVY FUNDED MARINE MAMMAL RESEARCH AND STUDIES FY 00-01

Submitted By:
Robert C. Gisiner, Ph.D.
Marine Mammal Science Program
Office of Naval Research

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10 May 2001

Dr. Robert H. Mattlin

Executive Director
Marine Mammal Commission
4340 East-West Highway, Room 905
Bethesda, MD 20814

Dear Dr. Mattlin,

The enclosed report is submitted in response to your annual letter to the Office of the Assistant Secretary of the Navy for Research, Development and Acquisition, requesting information on marine mammal related research conducted or supported by the Navy in the previous fiscal year (FY00), and planned for the current fiscal year (FY01).

Navy investment in marine mammal research for FY00-01 shows a continued high level of commitment to advancing our understanding of the unique biology of marine mammals and to promoting the conservation and recovery of these protected marine species.

This year's report is made available in electronic format (CD) to enable us to provide your office with more detailed information about each project, give you more flexibility in manipulating and reformatting the information for your own reporting needs, and reducing the amount of paper consumed during distribution of the report.

I think you will find this report not only more informative, but also easier to use, thanks largely to the efforts of Ms. Amanda Hansen who prepared this report. Any errors which appear in the report are mine; however, and I would appreciate your bringing them to my attention so that I may correct them in future reports.

Best wishes,

Robert C. Gisiner, Ph.D.
Marine Mammal S&T Program
Office of Naval Research

AGENCY SUMMARY
AND
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OFFICE
OF
NAVAL RESEARCH

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR05091**
Project Title:	**Image-based Processing for Biosonar Target Recognition**
Investigator(s):	**Altes, Richard A.**
Department or Division:	**N/A**
Performing Organization:	**Chirp Corporation**
Geographic Location of Study:	**Brown University**
Marine Mammal Species Involved:	**Atlantic Bottlenose Dolphin**
FY 00 Funding Level:	**90,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

(1) Construct biologically inspired acoustic images for target recognition/classification; (2) Improve image-based motion compensation; (3) Use cognitive (top-down, bottom-up) processing models for image sharpening; (4) Use sparse data (limited angular observation interval and angular sampling rate) to obtain recognizable images; (5) Evaluate feature images representing echo parameters other than reflectivity; (6) Investigate target/environment interactions with respect to image formation and interpretation.

ANNUAL PROGRESS REPORT

Name: Altes

Grant Number: N00014-98-C-0416

Title: Image-based processing for biosonar target recognition

Award Period: 01 SEP 98 – 31 AUG 01

Objectives:
(1) Construct biologically inspired acoustic images for target recognition/classification; (2) Improve image-based motion compensation; (3) Use cognitive (top-down, bottom-up) processing models for image sharpening; (4) Use sparse data (limited angular observation interval and angular sampling rate) to obtain recognizable images; (5) Evaluate feature images representing echo parameters other than reflectivity; (6) Investigate target/environment interactions with respect to image formation and interpretation.

Approach:
Chirp Corp. has designed a biologically inspired SAS imaging algorithm using Doppler tolerant, wideband signals, nonlinear, noncoherent echo combining, and parallel processing. The algorithm is easily implemented and yields recognizable images without exact motion compensation. Comparison with conventional SAS indicates that bioSAS is comparatively robust to unknown motion perturbations and to sparse angular sampling. BioSAS can be generalized to include features other than reflectivity. A rough/smooth feature image, for example, portrays smooth surfaces as blue and rough surfaces as red. The approach is to build on these results in order to solve Navy detection and classification problems, and to obtain insight into the detection/classification capabilities of dolphins and bats.

Accomplishments:
(1) A frequency-difference shadow feature image represents the shadow cast by a solid object, even if the object is in open water and is not near a ground plane or the bottom. Experience with conventional SAS systems has shown that such shadows are useful for object classification. Indeed, the new shadow feature images for two different mine-like objects are very different. The new shadow feature images are constructed by utilizing shadow differences at high and low frequencies. (2) The image-based tracker for motion compensation can be improved by iterative passes through stored echo data, although it also works well in non-iterative, single pass mode. (3) A top-down, bottom-up cognitive model that corresponds to algebraic reconstruction tomography can improve image resolution via iterative processing. Although iterative processing tends to be computationally burdensome, it can be accelerated via a massively parallel processor. Various techniques have been identified to utilize parallel processing capability for accelerating iterative optimization calculations. (4) The robustness of biologically

inspired SAS relative to standard coherent SAS has been demonstrated for sparse angular sampling without motion compensation. (5) Shadow compensation techniques have been improved to allow imaging of the shaded side of a target in drive-by mode.

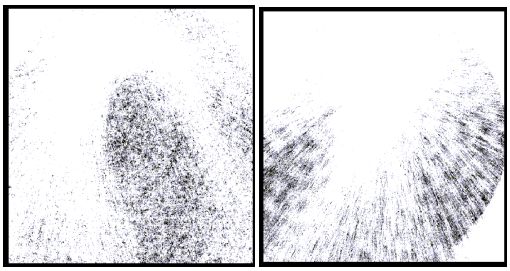
Significance:
The results indicate the possibility of an acoustic imaging technique that is comparatively easy to implement and that has very high area coverage rate. Multistatic imaging is possible, since the synthetic or physical array can be extremely sparse. New kinds of feature images can provide many different target and clutter representations for detection and classification. The impact for the Navy is the generation of conventional and feature images that can be used to easily recognize mines and other relevant objects with high area coverage rate and comparatively simple processing. Robust generation of images from relatively few aspects suggests mine hunting and ASW applications using multistatic arrays, helicopter-dipped sonars, UUV's, and sonabuoys. The simplicity of the biologically inspired SAS technique also makes it feasible for implementation by animal sonar systems. Sharpening via iterative top-down, bottom-up processing (with a reduced number of iterations via parallel processing) can provide a mechanism to convert low-resolution maps as in the superior colliculus into maps with much higher resolution at a higher processing center in the brain.

Work Plan:
(1) Continue to explore applications of the new frequency-difference shadow images. Can shadow images be processed to provide information about the back side of a target in drive-by mode? Can features for automatic target recognition be extracted from shadow images or can such features be accentuated on the image itself for the benefit of a human observer, e.g., via the use of different colors? (2) Continue to develop shadow compensation techniques such that the back side of a target can be seen without unduly emphasizing clutter at the same range. (3) Test and evaluate parallel processing methods for reduction of the number of iterations in top-down, bottom-up sharpening. (4) Further illustrate the robustness of biologically inspired SAS by comparing the point spread functions (range, cross-range ambiguity functions) of bioSAS and conventional SAS when aspects are sparsely sampled and when motion compensation is imperfect.

Publications, abstracts, technical reports, patents, and awards:
R.A. Altes, D.A. Helweg, and P.W. Moore, "Biologically Inspired Synthetic Aperture Imaging: The effects of changing sampling conditions on tomographic images constructed with wide band biologically inspired synthetic aperture sonar," Technical Document (in press), SPAWAR Systems Center, San Diego.

Frequency-difference Shadow Images for Target Classification

- Higher frequencies (shorter wavelengths) form darker, more distinctive acoustic shadows than lower frequencies.
- A shadow image is the difference between an image from high-pass echoes and an image from low-pass echoes.
- No ground plane or bottom is needed.
- Shadow images from different target types are very distinctive.



Shadow images of two different mines observed over 180º. Average direction of incident sound propagation is from the upper left.

Left: Manta. Right: Rockan.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR07057**
Project Title:	**Biomimetic SAS and Mine Classification – Signal Processing Models and Biological Experiments**
Investigator(s):	**Altes, Richard A.**
Department or Division:	**N/A**
Performing Organization:	**Chirp Corporation**
Geographic Location of Study:	**Brown University**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**13,451**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

(1) Collaborate with Brown Univ. and SPAWAR D351 to design experiments to verify/reject the hypothesis that dolphins and/or bats use synthetic aperture-like processing. Obtain new insights into bats' ten nano second jitter delay acuity measured at Brown. (2) Improve single-ping, aspect-invariant target classification and false alarm rejection for biomimetic sonar.

ANNUAL PROGRESS REPORT

Name: Altes

Grant Number: N00014-99-C-0356

Grant Title: Biomimetic SAS and Mine Classification – Signal Processing Models and Biological Experiments

Award Period: 07 July 99 – 04 May 01

Objectives:
(1) Collaborate with Brown Univ. and SPAWAR D351 to design experiments to verify/reject the hypothesis that dolphins and/or bats use synthetic aperture-like processing. Obtain new insights into bats' ten nanosecond jitter delay acuity measured at Brown. (2) Improve single-ping, aspect-invariant target classification and false alarm rejection for biomimetic sonar.

Approaches:
(1) One experiment uses simulated three-glint target echoes from a linear transducer array. A simpler design uses the fact that SAS avoids range-dependent degradation of azimuth resolution that occurs in a conventional sonar processor. If an animal views a target from multiple aspects, target details should be equally discernible at all ranges if SAS-like processing is used, but should become less discernible at longer ranges without SAS. (2) Physically meaningful features for aspect-dependent target classification are tested with a simple, biologically feasible classifier, using ordered maps of feature values as in the bat cortex. Feature values with large rotation-induced variation are ignored.

Accomplishments:
(1) For ten nanosecond jitter acuity, bat performance is the same as an ideal receiver at the measured noise level. For nonzero internal noise, performance is better than optimum. One possible explanation is sequential detection with an optimum stopping rule. Although the bats use an average of five pulses, their measured performance could be equivalent to ten or more pulses, where early decisions are justified by initial measurements that overwhelmingly favor the jitter or non-jitter hypothesis. Another explanation involves an important new insight for range estimation. Jitter discrimination performance is improved by averaging the output of an optimum delay estimator with the outputs of slightly suboptimum delay estimators, where the output noise of the suboptimum estimators is partially decorrelated from the output noise of the optimum estimator. Such averaging requires 22% lower SNR than the optimum estimator alone. Observed jitter performance is thus possible with nonzero internal noise level (22% of the external level). (2) Several new features for aspect-independent discrimination of mine-like targets have been found, yielding four features altogether. When all four of the features are used, the error probability of the biomimetic classifier for single-ping

discrimination between four different mines is 3×10^{-3}. All the features that have been found to date are based on resonance or autoregressive echo models.

Significance:
(1) Averaging the optimum delay estimate with several slightly suboptimum estimates explains bat jitter discrimination and leads to better-than-optimum delay estimators for human-made systems. These systems include radar/sonar tracking, motion sensing, and global positioning. The same averaging concept is applicable to frequency and phase estimates, yielding improved performance of radar, sonar, and communication systems. A highly significant result (better-than-optimum estimation) has been obtained by trying to explain bat jitter sensitivity. The corresponding biological model is plausible, since a biological sensor is likely to approximate an ideal operation with the average of a parallel set of approximate versions of the ideal operation. Further proof of this concept may be obtained by translating the bat experiments to dolphins. (2) For single-ping mine classification, the recently discovered features yield a false alarm rate that should significantly improve the performance of mine hunting sonar systems.

Work Plan:
(1) Continue analysis and testing of the better-than-optimum estimator, and try to design tests for its presence in bats and dolphins. Utilize range independence of SAS azimuth resolution to construct behavioral experiments on dolphins and bats in collaboration with J.Simmons, D. Helweg, and P.Moore. One such experiment is allow a dolphin to swim freely behind a visually opaque, acoustically transparent barrier, and to test discrimination of three-glint targets that are presented with random rotations from one trial to the next. If the animals use SAS, discrimination performance should be independent of range. (2) Investigate additional features to further reduce false alarm rate for mine hunting. Try to incorporate newly discovered features into generalized SAS images like the colored rough/smooth feature images that have been developed by the PI.

Publications, abstracts, technical reports, patents, and awards:
R.A. Altes, D.A. Helweg, and P.W. Moore, "Biologically Inspired Synthetic Aperture Imaging: The effects of changing sampling conditions on tomographic images constructed with wide band biologically inspired synthetic aperture sonar," Technical Document (in press), SPAWAR Systems Center, San Diego.Annual

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00956**
Project Title:	**Alternative Mine Detection and Classification Technologies**
Investigator(s):	**Brill, Randy**
Department or Division:	**Biosciences Division D35**
Performing Organization:	**SSC, San Diego**
Geographic Location of Study:	**San Diego Bay, CA**
Marine Mammal Species Involved:	***Tursiops truncatus***
FY 00 Funding Level:	**400,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

The goals of this project include the development of signal processing algorithms that utilize the signal characteristics of the dolphin echo to classify proud and buried mine-like targest. This project will investigate the dolphin's basic parameters of hearing sensitivity to quantify mechanisms which result in its capability to extract and process highlights or features in target echos.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01154**
Project Title:	**Development of a Miniature Acoustic Recording Tag to Assess Marine Wildlife Response to Sound**
Investigator(s):	**Burgess, William C**
Department or Division:	**N/A**
Performing Organization:	**Greeneridge Sciences, Inc.**
Geographic Location of Study:	**Santa Barbara, CA**
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**159,799**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

Develop easy-to-use acoustic recording instrumentation, sufficiently small and lightweight to be attached to a variety of marine species, which will accurately measure acoustic stimuli and potential responses for individual animals. These measurements will allow the subjects' acoustic sensitivity to be quantified.

ANNUAL PROGRESS REPORT

Na**me:** Burgess

Grant Number: N00014-99-C-0170

Title: Development of a Miniature Acoustic Recording Tag to Assess Marine Wildlife Response to Sound

Award Period: 1 June 1999 – 31 May 2002

Objective:
Develop easy-to-use acoustic recording instrumentation, sufficiently small and lightweight to be attached to a variety of marine species, which will accurately measure acoustic stimuli and potential responses for individual animals. These measurements will allow the subjects' acoustic sensitivity to be quantified.

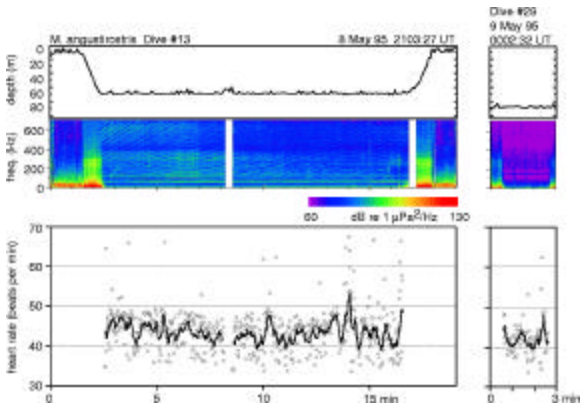
Approach:
Larger acoustic recording tags developed under prior ONR 6.1 support obtained acoustic stimulus and response data from northern elephant seals. These data validated the concept of quantifying acoustic sensitivity with recording tags, but the instrument package was too large and heavy to be attached to smaller species, or to be used with the airborne or suction-cup delivery methods necessary for attachment to whales. The current effort applies several miniaturization techniques to obtain a small resin-encased solid-state recording package with typical bandwidths of 10-1000 Hz for deployments of a few days.

Accomplishments:
This project commenced in June 1999. As of 31 May 2000, the electronic design was nearly complete and about to be delivered to a printed-circuit board specialist for layout of the alpha-test prototype. A benchtop prototype was assembled, including all critical circuits, and was successfully tested with an initial version of the embedded data acquisition software.

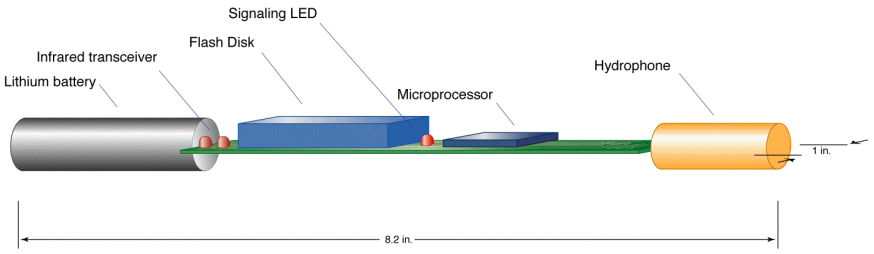
Significance:
The Navy faces increasing regulation due to the potential impact of operational sounds on protected marine wildlife. This regulatory concern is exacerbated by our insufficient knowledge of protected species' acoustic sensitivity. As a result, regulations have been written and interpreted from a conservative standpoint to responsibly protect these species. Quantification of acoustic sensitivity for different species would permit refinement of regulations, with potentially reduced impact on Naval operations. The miniature tag under development will provide the bioacoustic research community with a commercially available tool to obtain these measurements.

Work Plan:
The second year of development (June 2000 through May 2001) will begin with construction of the alpha-test prototype, followed by extensive laboratory and field testing. Results from the field test will be documented and used to improve the tag design, leading to a beta-test prototype to be applied in a separately funded field biology program.

Publications, Abstracts, Technical Reports, Patents & Awards:
None (nor any expected from this initial design stage).



- Testbed "Compact Acoustic Probe" (CAP) developed in 1995-1997 under ONR 6.1 support to Woods Hole Oceanographic Institution (WHOI) and the University of California at Santa Cruz),and a postdoctoral fellowship from the Monterey Bay Aquarium Research Institute (MBARI)
- Detection of cardiac sounds allowed measurement of heart rate during exposure to vessel noise
- While absence of flow noise suggests change of behavior in association with vessel noise, heart rate does not show correlation with passage of vessels



Maximum signal frequency:	14 kHz
Maximum depth:	1000 m
Current when sampling at 2 kHz (estimated):	10 mA at 3V
Maximum storage:	288 Mb
Active deployment lifetime at 2 kHz sample rate:	20 hours

NOT SHOWN:
- Pressure Transducer
- Thermistor

This concept slide shows the current (July 2000) configuration planned for the miniaturized acoustic recording tag being developed under this contract. The two most significant sources of miniaturization are (a) the flash disk, which is a 32-pin DIP device that operates as a disk drive with capacities up to 288 Mb, and (b) low-power electronics enabling the entire device to be operated from a single lithium cell. At present we are exploring the possibility of replacing the AA-sized cell with a prismatic lithium cell placed underneath the circuit board. This would reduce the length by 2 inches (to 6.2 inches) while increasing the width by only about a quarter inch (to 1.25 inches).

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR09457**
Project Title:	**Examination of Vocal and Underwater Behavior of Blue Whales Using a Suction-Cup Attached CRITTERCAM**
Investigator(s):	**Calambokidis, John**
Department or Division:	**N/A**
Performing Organization:	**Cascadia Research**
Geographic Location of Study:	**Monterey Bay, CA**
Marine Mammal Species Involved:	**Blue Whales**
FY 00 Funding Level:	**17,848**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective of this research is to better understand the migratory and feeding behavior of blue whales, a highly migratory top level consumer in marine exosystems around the globe, and to understand how acoustic and visual cues play a role in ciritical behaviors associated with feeding, migration and social interaction. The performer will work with National Geographic and other collaborators to place an animal-carried video camera on blue whales and integrate the video data with other observational and environmental data to construct a more complete understanding of blue whale ecology.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**99PR02636**
Project Title:	**Monitoring Whales Using the Pt Sur Acoustic Array – A Feasibility Study**
Investigator(s):	**Chiu, Ching-Sang**
Department or Division:	**Oceanography**
Performing Organization:	**Naval Postgraduate School**
Geographic Location of Study:	**Monterey, CA**
Marine Mammal Species Involved:	**Blue whales**
FY 00 Funding Level:	**20,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To investigate the feasibility of automating the detection, tracking and censusing of blue whale (*balaenoptera musculus*) vocalizations over a large coastal region using a decommissioned IUSS hydrophone array at Pt Sur, California.

ANNUAL PROGRESS REPORT

Name: Chiu

Grant Number: N0001499WR20050

Title: Monitoring Whales Using the Pt Sur Acoustic Array – A Feasibility Study

Award Period: 1 June 1999 - 30 September 1999 (4 months)

Objective:
To investigate the feasibility of automating the detection, tracking and censusing of blue whale (*balaenoptera musculus*) vocalizations over a large coastal region using a decommissioned IUSS hydrophone array at Pt Sur, California.

Approach:
In 1997, a comprehensive experiment was conducted to collect both near and far-field acoustic data of blue whale vocalizations, as well as background physical oceanographic data. Acoustic modeling information was used to transform the near-field towed array data back to the actual transmitted signal at the source (whale) location. This reconstructed source signal was then used as input for matched signal processing techniques on the far-field acoustic data to establish detection and classification characteristics of the receiver system.

Accomplishments:
We have completed matched signal processing on Pt Sur far-field data from 1998, using the 1997 reconstructed source signals. Matched signal results for both high and low-noise periods show considerable promise for classic auto-detection methods, however considerable false-alarms are observed when using simple threshold detectors. A multi-scale discriminant (wavelet) operator is currently under review to determine the improved call detection and classifications that may be realized.

Significance:
Traditional census methods require visual observation techniques, which require the focal animal to be on the surface while the observer is within visual range, and statistical methods are used to estimate population size. Acoustic methods for detecting and discriminating marine mammals have a much larger detection range and no limitations on the animal's position in the water column. These acoustic results can be used in conjunction with the visual detections to reduce the statistical error when calculating total population sizes.

When the acoustic method is proven feasible, it will provide valuable information on the counts and transit paths of blue whales. This project also provides a dual-use example of existing Navy systems used outside their original mission objectives. With the locations

and numbers of whales present inside an operational area, the Navy can meet today's marine mammal compliance issues during operational exercises, etc.

Work Plan:

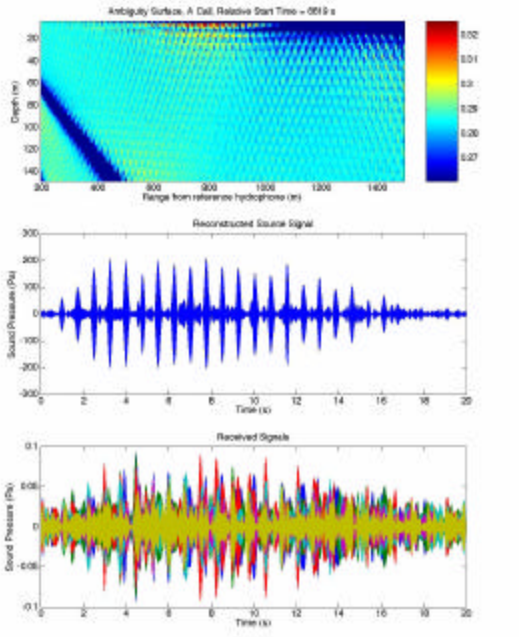
The major goal of the next 12 month period will be to secure funding and repair of the array cable, which has 90% severed and expected to fail completely with the year. Data from the NPS Ocean Acoustic Observatory, Pt Sur will continue to be archived as available for review and processing. Our goals are to compile call detection tallies for monthly, annual and inter-annual variability, however this project is currently unfunded, so progress will be on a "time-available" basis.

Publications, Abstracts, Technical Reports, Patents & Awards:

Chiu, C.-S., et. Al., "Detection and Censusing of blue whale vocalizations along the central California coast using a former SOSUS array", J. Acoustic. Soc. Am., 106 (4.2), 2163, 1999.

Chiu, C.-S., Collins, C., "Experience with Reactivated Pt Sur Site", SERDP IUSS Dual-Uses Program wrap-up meeting, 28-29 September 1999.

Delory, E., J. Potter, C. Miller, C. Chiu, "Detection & Classification of blue whale 'A' & 'B' calls in the NE Pacific using a multi-scale discriminant operator," Proceedings of the 13 Biennial Conference on the Biology of Marine Mammals, 1999.



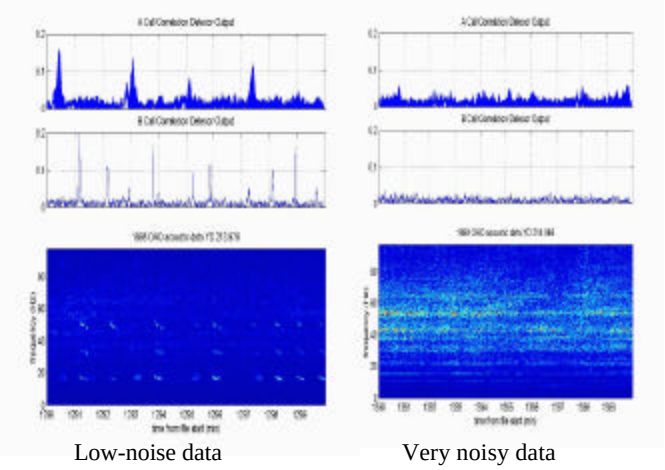
The deverberation of a blue whale A call. An ambiguity surface (top) was calculated from applying a matched signal method to the signals (bottom) received by the different hydrophones of an array. The highest correlation grid point gave the best estimate of the whale location. With the location known, the received multipath signals were then deverberated to reconstruct the source signal produced by the whale (Middle).

Blue Whale Call
Detection and False-Alarm Classifications

"A" call detection

"B" Call detection

OAO single phone data spectrogram



Low-noise data with whale calls

Very noisy data without whale calls

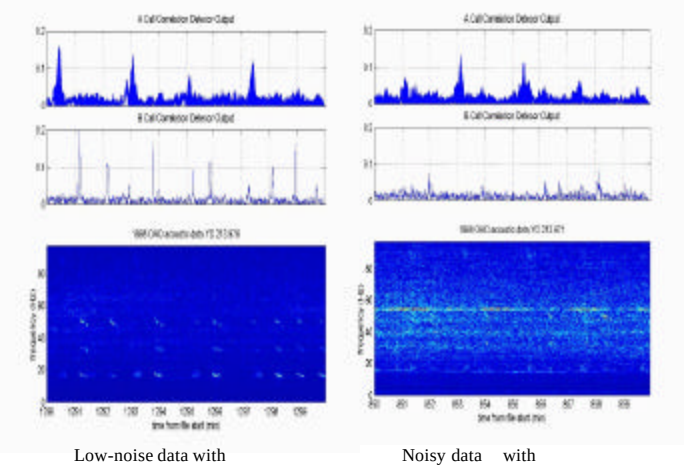
Sample detection results for blue whale "A" and "B" calls for 2 periods of data during 1998. This viewgraph shows the accurate detection of both "A" & "B" calls during a 'whale present' (true detection) condition, as well as the lack of detection when no whale is present (a false-alarm opportunity).

Blue Whale "A" and "B" call
Signal-to-Noise Robustness

"A" call detection

"B" Call detection

OAO single phone data spectrogram



Low-noise data with whale calls

Noisy data with whale calls

Sample detection results for blue whale "A" and "B" calls for 2 periods of data with different signal-to-noise characteristics. During periods of low noise, the detectors work very well (as one would expect) and the "A" and "B" calls are correctly classified and detected. During higher noise levels (primarily shipping noise), both "A" and "B" calls can still be detected, but both results require a smarter technique to determine a correct detection threshold. Due to the lower detection rates during high noise periods, a multi-scale descriminant operator is being investigated using wavelets.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00724**
Project Title:	**New Directions in the Study of Low-Frequency Sound in Baleen Whales**
Investigator(s):	**Clark, Christopher W.**
Department or Division:	**Laboratory of Ornithology**
Performing Organization:	**Cornell University**
Geographic Location of Study:	**Gulf of California**
Marine Mammal Species Involved:	**Blue, Fin whales**
FY 00 Funding Level:	**82,758**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objectives are to understand the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales, and to examine whether low-frequency vocalization rates can be used to indicate the presence of animals and number of individuals in an area.

ANNUAL PROGRESS REPORT

Name: Clark

Grant Number: N00014-99-1-0244

Title: New Directions in the Study of Low-Frequency Sound in Baleen Whales

Award Period: January 1999- December 2000 (12 months)

Objective:
The objectives are to understand the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales, and to examine whether low-frequency vocalization rates can be used to indicate the presence of animals and number of individuals in an area.

Approach:
The working hypotheses are that sounds are produced for communicating, navigating, and finding food. To test these hypotheses we are using an integrated approach involving scientists with expertise in whale acoustics; foraging and tagging; vessel survey; biopsy sampling; and photo-ID. This combination allows us to place the various vocal behaviors, often from known individuals, within the proper ecological framework. By this procedure, interpretations of vocal functions are related to the proper context within which the behavior occurs.

Accomplishments:
Field research was conducted for 28 days in winter/spring 2000. Six pop-ups were deployed in the field for 18 days. During daily fieldwork, we integrated information on prey fields, water temperature, marine mammal sighting density, individual diving/movement patterns, and acoustic activity (from 16-element towed array). Directions to individual vocal animals were computed in realtime and coordinated with visual sightings to direct the biopsy team to vocal animals. All vocal fin whales (n=9) were males. Systematic visual survey and Photo-ID efforts were conducted. These with the pop-up data allow us to compare the total number of animals utilizing the study area by three independent methods.

Significance:
The new evidence from the Sea of Cortez shows that there are general positive associations between levels of male sound production, food distribution and feeding. Contrary to previous assumptions that these sounds were a male reproductive display, the sounds occur during feeding activity, suggesting that the functional context might be broader than breeding. The relevance of these new findings is that the impact of man-made sounds on whale communication must be extended into the feeding context which involves a significant portion of the year in various habitats. By bringing the specific acoustic behaviors of individuals within the appropriate ecological context, we can now focus on the

most appropriate hypothesis regarding the biological importance of these common vocal productions (e.g., they are detected throughout the oceans on IUSS). This should lead to a more rigorous understanding on the impact of human-produced LFS on large whales.

We now have data that will allow us to directly measure natural variability in male sound production,. information that is valuable for models (e.g., AIM) used to predict acoustic impact for mitigation purposes.

We can now compare estimates of relative abundance based on three independent sampling methods (acoustic monitoring, visual survey, and photo-id), collected simultaneously and systematically for a relatively well-defined population of animals. These results provide a quantitative basis for evaluating the effectiveness of acoustic techniques to monitor marine mammal seasonal distributions and occurrence on a broader scales. This addresses the need to reliably and efficiently determine the presence and density of animals, and to reliably detect changes in their distribution and abundance under conditions when human-produced LFS is present.

Work Plan:
We have completed the two seasons of field effort as originally planned. The third year will be spent analyzing and integrating the data, and writing papers on our results. The acoustic data sets will be carefully analyzed to determine the degree of association between vocal activity and whale behavior for individual whales, in relation to daily food distribution within portions of the study area, and in relation to daily food abundance throughout the entire study area over the month-long field season. We will initially focus on the nine males for which biopsies and focal follows were obtained. Daily distributions and behaviors of vocal animals will be compared with patterns of food distribution. Daily counts of minimum/maximum numbers of vocal males will be compared to estimates from the visual survey and photo-ID data sets.

Publications, Abstracts, Technical Reports, Patents, and Awards (yr 2):
Croll, D.A., C.W. Clark, J. Calambokidis, W.T. Ellison, and B.R. Tershy. Accepted. Effect of anthropogenic low frequency noise on the foraging ecology of *Balaenoptera* whales. Ecological Applications.

Clark , C.W. and Ellison, W.T. accepted. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. (eds. J. Thomas and R. Kastelein).

Clark. C.W., Croll, D., Tershy, B., Acevedo, A., Gedamke, J. and Urban-Ramirez, J. Relationship Between Fin Whale Vocal Activity, Distribution, Abundance, and Prey Distribution in the Sea of Cortez, Mexico. Presentation at the 1999 Marine Mammal Conference, Maui, HI.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01156**
Project Title:	**Tools for the Assessment of Marine Mammal Critical Habitats**
Investigator(s):	**Crocker, Daniel**
Department or Division:	**Biology**
Performing Organization:	**University of California, Santa Cruz**
Geographic Location of Study:	**Gulf of California**
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**49,560**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective of this project is to add databases and data management tools to expand the capabilities of an existing prototype mapping display system. The system will be used to display the movements of a variety of wide-ranging marine mammals.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00723**
Project Title:	**New Directions in the Study of Low-Frequency Sound in Baleen Whales**
Investigator(s):	**Croll, Don**
Department or Division:	**Institute of Marine Sciences**
Performing Organization:	**University of California, Santa Cruz**
Geographic Location of Study:	**Gulf of California**
Marine Mammal Species Involved:	**Blue whale, Fin whale**
FY 00 Funding Level:	**204,041**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objectives are to understand the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales, and to examine whether low-frequency vocalization rates can be used to indicate the presence of animals and number of individuals in an area.

ANNUAL PROGRESS REPORT

Name: Croll

Grant Number: N00014-99-1-0192

Title: New Directions in the Study of Low-Frequency Sound in Baleen Whales

Award Period: January 1999- December 2000 (12 months)

Objective:
The objectives are to understand the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales, and to examine whether low-frequency vocalization rates can be used to indicate the presence of animals and number of individuals in an area.

Approach:
The working hypotheses are that sounds are produced for communicating, navigating, and finding food. To test these hypotheses we are using an integrated approach involving scientists with expertise in whale acoustics; foraging and tagging; vessel survey; biopsy sampling; and photo-ID. This combination allows us to place the various vocal behaviors, often from known individuals, within the proper ecological framework. By this procedure, interpretations of vocal functions are related to the proper context within which the behavior occurs.

Accomplishments:
Field research was conducted for 28 days in winter/spring 2000. Six pop-ups were deployed in the field for 18 days. During daily fieldwork, we integrated information on prey fields, water temperature, marine mammal sighting density, individual diving/movement patterns, and acoustic activity (from 16-element towed array). Directions to individual vocal animals were computed in realtime and coordinated with visual sightings to direct the biopsy team to vocal animals. All vocal fin whales (n=9) were males. Systematic visual survey and Photo-ID efforts were conducted. These with the pop-up data allow us to compare the total number of animals utilizing the study area by three independent methods.

Significance:
The new evidence from the Sea of Cortez shows that there are general positive associations between levels of male sound production, food distribution and feeding. Contrary to previous assumptions that these sounds were a male reproductive display, the sounds occur during feeding activity, suggesting that the functional context might be broader than breeding. The relevance of these new findings is that the impact of man-made sounds on whale communication must be extended into the feeding context that involves a significant portion of the year in various habitats. By bringing the specific acoustic behaviors of individuals within the appropriate ecological context, we can now focus on the most

appropriate hypothesis regarding the biological importance of these common vocal productions (e.g., they are detected throughout the oceans on IUSS). This should lead to a more rigorous understanding on the impact of human-produced LFS on large whales.

We now have data that will allow us to directly measure natural variability in male sound production; information that is valuable for models (e.g., AIM) used to predict acoustic impact for mitigation purposes.

We can now compare estimates of relative abundance based on three independent sampling methods (acoustic monitoring, visual survey, and photo-id), collected simultaneously and systematically for a relatively well-defined population of animals. These results provide a quantitative basis for evaluating the effectiveness of acoustic techniques to monitor marine mammal seasonal distributions and occurrence on broader scales. This addresses the need to reliably and efficiently determine the presence and density of animals, and to reliably detect changes in their distribution and abundance under conditions when human-produced LFS is present.

Work Plan:
We have completed the two seasons of field effort as originally planned. The third year will be spent analyzing and integrating the data, and writing papers on our results. The acoustic data sets will be carefully analyzed to determine the degree of association between vocal activity and whale behavior for individual whales. This analysis will be conducted in relation to daily food distribution within portions of the study area, and food abundance throughout the entire study area over the month-long field season. We will initially focus on the nine males for which biopsies and focal follows were obtained. Daily distributions and behaviors of vocal animals will be compared with patterns of food distribution. Daily counts of minimum/maximum numbers of vocal males will be compared to estimates from the visual survey and photo-ID data sets.

Publications, Abstracts, Technical Reports, Patents & Awards:
Presentations:

Clark. C.W., Croll, D., Tershy, B., Acevedo, A., Gedamke, J. and Urban-Ramirez, J. Relationship Between Fin Whale Vocal Activity, Distribution, Abundance, and Prey Distribution in the Sea of Cortez, Mexico. Presentation at the 1999 Marine Mammal Conference, Maui, HI.

Croll, D.A., S. Benson, and B. Marinovic. Foraging ecology of rorquals in the California Current. Presentation at the 1999 Marine Mammal Conference, Maui, HI.

Croll, D.A., and B. Marinovic. El Niño, Krill and Whales -not the story you might expect. Hopkins Marine Station Apr. 2000

Clark, K., and B. Marinovic. Affects of coastal upwelling on the dispersal and recruitment of krill larvae to adult populations within the Central California Current System. Larval 2000, UCSC Jun. 2000

Books:

Chapter: Clark and Ellison, Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements

Croll, D.A. and B.R. Tershy. Filter feeding. Encyclopedia of marine mammals.

Papers:

Croll, D.A., C.W. Clark, J. Calambokidus, W.T. Ellison, and B.R. Tershy. Accepted. Effect of anthropogenic low frequency noise on the foraging ecology of *Balaenoptera* whales. Ecological Applications.

Williams, T.M., R.W. Davis, L.A. Fuiman, J. Francis, B.J. LeBoeuf, M. Horning, J. Calambokidis, and D.A. Croll. 2000. Sink or swim strategies to conserve energy in diving marine mammals. Science 288:133-136.

Croll, D.A., A. Acevedo, B.R. Tershy, and J. Urban-Ramirez. Accepted. Diving behavior of rorquals: is dive duration shorter than predicted? J. Comp. Biochemistry and Physiology B.

Croll, D.A., B. Marinovic, S. Benson, and F.P. Chavez,. Submitted. From wind to whales: trophic links in the California Current coastal upwelling ecosystem. Ecology.

Jones, B., and D.A. Croll. Submitted. Noise pollution and marine mammals: an approach to regulating sound in the ocean. J. Wildlife Management.

Acevedo, A., D.A. Croll, and B.R. Tershy. Submitted. The cost of being the largest animal on earth: short foraging times of blue whales. Science.

Benson, S.R., D.A. Croll, B. Marinovic, F. Chavez, and J.T. Harvey. Submitted. Variability of the cetacean assamblage of a coastal upwelling center spanning an El Nino event. Deep Sea Research.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01157**
Project Title:	**AIM Model Developments**
Investigator(s):	**Ellison, William**
Department or Division:	**Analysis & Applied Research**
Performing Organization:	**Marine Acoustics Inc.**
Geographic Location of Study:	**N/A (modeling)**
Marine Mammal Species Involved:	**N/A (modeling)**
FY 00 Funding Level:	**70,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The proposed work is intended to model the three-dimensional movements of a given marine mammal species as it travels, feeds and carries out other behaviors. These movement patterns will be merged with existing Navy and other high-resolution parabolic equation models of underwater sound propagation to yield the maximum, cumulative and equivalent dosage of sound exposure for a given marine mammal track.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00725**
Project Title:	**Low frequency marine mammal hearing thresholds in response to acoustic pressure and particle velocity**
Investigator(s):	**Finneran, James J.**
Department or Division:	**D351**
Performing Organization:	**Space and Naval Warfare Systems Center, San Diego**
Geographic Location of Study:	**San Diego, California**
Marine Mammal Species Involved:	**Bottlenose dolphin, White whale, California sea lion**
FY 00 Funding Level:	**115,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To determine the relative contributions of acoustic pressure and particle velocity to the low-frequency, underwater hearing abilities of the bottlenose dolphin (*Tursiops truncatus*), white whale (*Delphinapterus leucas*), and California sea lion (*Zalophus californianus*).

ANNUAL PROGRESS REPORT

Name: Finneran

Grant Number: N0001499WX20503

Title: Low frequency marine mammal hearing thresholds in response to acoustic pressure and particle velocity

Award Period: 1 March 1999 – 30 September 2000

Objective:
To determine the relative contributions of acoustic pressure and particle velocity to the low-frequency, underwater hearing abilities of the bottlenose dolphin (*Tursiops truncatus*), white whale (*Delphinapterus leucas*), and California sea lion (*Zalophus californianus*).

Approach:
A behavioral response paradigm is used to measure underwater hearing thresholds while manipulating the pressure/velocity (*p*/*v*) relationship by (1) varying the distance within the hydrodynamic nearfield of a single source and (2) using an active sound control system. Animal subjects are trained to produce audible "whistles" in response to hearing test tones. The source levels are varied, while maintaining the proper *p*/*v* relationship, in a staircase procedure until the threshold is determined.

Accomplishments:
Masked hearing thresholds at 100 and 300 Hz were measured in a bottlenose dolphin and white whale at distances of 1, 2, and 4 m from a single underwater sound projector; over these distances the specific acoustic impedance ratio varied from approximately –10 to 0 dB at 100 Hz and -3 to 0 dB at 300 Hz. Individual hearing test trials consisted of a 3.5-s noise burst alone (N) or a noise burst with a 1-s tone (S+N). Subjects were trained to produce an audible whistle in response to S+N trials and to remain silent for N trials. Thresholds were estimated using an up-down staircase procedure. Resulting data showed no significant differences between pressure thresholds measured at the three different source distances for either test subject. An active sound control system featuring two sources is now being used to generate different *p*/*v* test conditions. This system allows a larger range of impedance ratios to be generated at the test site. Hearing threshold measurements are currently underway with this test configuration. In addition, a California sea lion has been trained to emit vocal responses to hearing test tones as a preliminary to threshold measurements.

Significance:
Concern that man-made noise in the ocean may compromise the hearing or affect the behavior of marine mammals has given rise to legal actions that have resulted in costly delays and expensive modification to Navy projects. Also, the discovery of dead whales

often brings into question possible involvement of human activities, especially naval activities, in the mortality event. At present, there are insufficient data to allow confident predictions about the effects of low-frequency underwater sound on marine mammals. The information resulting from this study will shed light on the basic principles of underwater hearing in the species studied, provide a basis for meaningful comparison of hearing thresholds in marine and terrestrial mammals, and facilitate the development of safe limits of low-frequency, underwater noise exposure for marine mammals.

Work Plan:

Hearing threshold measurements will be conducted at 300 Hz using *p*/*v* ratios varying from conditions of low pressure/high particle velocity to high pressure/low particle velocity, as well as both individual sources alone. Measured thresholds and acoustic field measurements will be analyzed to determine the relative sensitivity of each subject to acoustic pressure, particle velocity, and acoustic intensity. Sea lion thresholds will also be measured at various *p*/*v* ratios using the active sound control system.

Publications, Abstracts, Technical Reports, Patents & Awards:

Finneran, J. J. and Ridgway, S. H. (**2000**). "Low frequency masked hearing thresholds for a bottlenose dolphin (*Tursiops truncatus*) and white whale (*Delphinapterus leucas*) within the farfield and hydrodynamic nearfield," Journal of the Acoustical Society of America, **107**, 2785(A), presented at the 139th Meeting of the Acoustical Society of America, Atlanta, GA, May 2000.

Finneran, J. J., Carder, D. A., Ridgway, S. H., and Schlundt, C. E. (**1999**). "Technique for the generation and frequency compensation of band-limited white noise and its application in studies of masked hearing thresholds," Journal of the Acoustical Society of America, **106**(4), 2130(A), presented at the 138th Meeting of the Acoustical Society of America, Columbus, OH, November 1999.

Finneran, J. J., Oliver, C. W., Schaefer, K. M., and Ridgway, S. H. (**2000**). "Source levels and estimated yellowfin tuna (*Thunnus albacares*) detection ranges for dolphin jaw pops, breaches, and tail slaps," Journal of the Acoustical Society of America, **107**(1), 649–656.

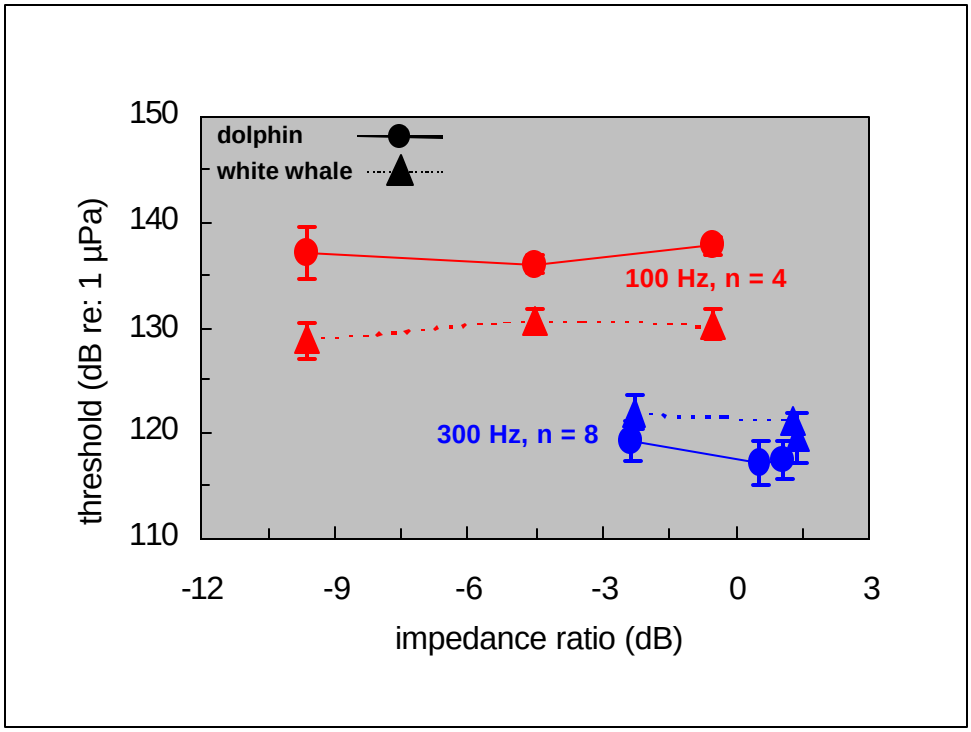
Finneran, J. J., Schlundt, C. E., Carder, D. A., Clark, J. A., Young, J. A. Gaspin, J. B., and Ridgway, S. H. (**2000**). "Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and white whales (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions," Journal of the Acoustical Society of America **108**(1), 417–431.

Oliver, C. W., Finneran, J. J., and Schaefer, K. M. (**1999**). "Low-frequency acoustic detection of yellowfin tuna, *Thunnus albacares*, and possibly dolphins by yellowfin tuna, in the eastern tropical Pacific Ocean," presented at the 13th Biennial Conference on the Biology of Marine Mammals, November 28–December 3, 1999.

Schlundt, C. E., Finneran, J. J., Carder, D. A., and Ridgway, S. H. (**2000**). "Temporary shift in masked hearing thresholds (MTTS) of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones," Journal of the Acoustical Society of America **107**(6), 3496–3508.

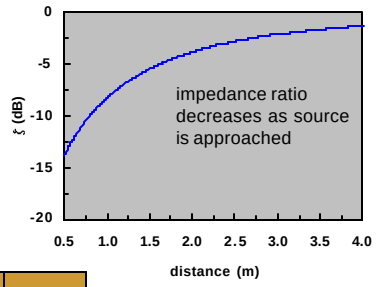
Schlundt, C. E., Finneran, J. J., Carder, D. A., and Ridgway, S. H. (**1999**). "Masked hearing thresholds and critical bandwidths for dolphins and a white whale at 20 and

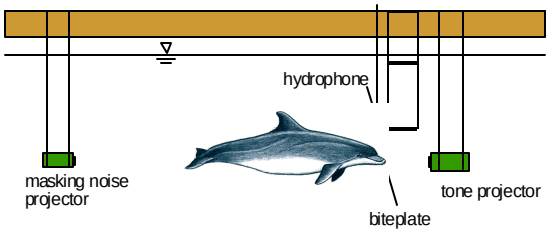
30 kHz," Journal of the Acoustical Society of America **106**(4), 2190(A), presented at the 138th Meeting of the Acoustical Society of America, Columbus, OH, November 1999.



Exp. I: changing source distances

- Particle velocity increases faster than pressure as source is approached
- Different distances have different impedance ratios



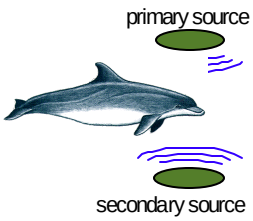


impedance ratio $z = p / r_{cv}$

Exp. II: active sound control system

- Use two sound sources
- Manipulate amplitude/phase of second source to interfere with first source
  - Waves arrive out-of-phase — velocity maximum
  - Waves arrive in-phase — pressure maximum

TOP VIEW



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR07234**
Project Title:	**Tools and Techniques for Marine Animal Sound Analysis**
Investigator(s):	**Fox, Christopher**
Department or Division:	**N/A**
Performing Organization:	**NOAA Pacific Marine Enviornmental Laboratory (PMEL)**
Geographic Location of Study:	
Marine Mammal Species Involved:	**none**
FY 00 Funding Level:	**38,178/104,635**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective of this project is to develop an integrated suite of PC-based acoustic signal processing tools to enable the novice and moderately experienced bioacoustician to collect and analyze marine mammal acoustic data.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR03202**
Project Title:	**Biomechanics and energetics of locomotion in rigid-bodied fishes**
Investigator(s):	**Gordon, Malcolm S**
Department or Division:	**Organismic Biology, Ecology, Evolution**
Performing Organization:	**University of California, Los Angeles**
Geographic Location of Study:	**Los Angeles, CA**
Marine Mammal Species Involved:	**Rigid-bodied fish**
FY 00 Funding Level:	**90,707**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To quantitatively understand the biomechanical and hydrodynamic bases for the unusually stable and well controlled swimming of rigid-bodied ostraciid fishes (boxfish, trunkfish, cowfish) in turbulent shallow-water marine environments. This understanding should facilitate the development of biomimetic robotic autonomous underwater vehicles (AUVs) based upon the design features and principles they embody.

ANNUAL PROGRESS REPORT

Name: Gordon

Grant Number: N00014-96-1-0607

Title: Biomechanics and energetics of locomotion in rigid-bodied fishes

Award Period: 1 March 1996 - 24 November 2001

Objective:
To quantitatively understand the biomechanical and hydrodynamic bases for the unusually stable and well controlled swimming of rigid-bodied ostraciid fishes (boxfish, trunkfish, cowfish) in turbulent shallow-water marine environments. This understanding should facilitate the development of biomimetic robotic autonomous underwater vehicles (AUVs) based upon the design features and principles they embody.

Approach:
Our administrative approach involves a close symbiotic working relationship between the PIs laboratory at UCLA and the laboratory of Prof. M. Gharib at the California Institute of Technology, Pasadena. We collaborate on all important aspects of the work. We also have twice yearly joint meetings between the participants and our outside consultants. Laboratory studies include: biomechanical studies in water tunnels of swimming in live fishes using high-speed digital video recordings and image analyses; flow visualization studies in water and wind tunnels using 2-D and 3-D digital particle imaging velocimetry (DPIV) around rapid prototyped anatomically exact models of fish bodies; force balance and surface pressure distribution studies of model behavior in wind tunnels; and DPIV studies around model fish fins made of materials with varying compliance.

Accomplishments:
Employed the two postdoctoral research associates (Drs. J.R. Hove and I.K. Bartol) who are our principal hands-on experimenters. Obtained fresh frozen specimens of four species of Caribbean ostraciid fishes having body shapes and sizes greatly different from that of the Hawaiian boxfish studied previously. Did CAT scans of several of these specimens and produced rapid prototyped models of their bodies for use in DPIV, force balance, and surface pressure distribution studies. Began studies of all three kinds, plus initial studies of fin properties. Presented two invited symposium papers describing major results of earlier work. Published one paper based on earlier work and wrote up and submitted for publication two major papers describing specifics of earlier work (one of these now in press, the other in review). Produced a 7-minute video summarizing many of the major findings of our earlier work. This video was submitted to Dr. Gisiner and was used to illustrate the symposium presentations. Prepared three additional papers for presentation at another international symposium to take place in August 2000.

Significance:
Ostraciid fishes are rigid-bodied multi-propulsor natural AUVs that are unusually stable and well controlled in swimming as compared with almost all other groups of fishes. They accomplish this by using a variety of biomechanical and biofluiddynamic methods and mechanisms. We are beginning to understand these methods and mechanisms. The collaboration between the two lab groups is facilitating rapid progress in obtaining useful results and is permitting the use of cutting-edge innovative approaches and techniques never before applied to work on fish swimming. Feedback received from people within ONR indicates that our results are contributing to substantial revisions in agency thinking concerning optimal directions for continuing research on biomimetic robotic AUVs.

Work Plan:
Primary emphasis will be given to completing the water- and wind-tunnel based studies of the anatomically exact models of four morphologically distinct body forms of ostraciid fishes: the Hawaiian boxfish (trapezoidal in cross-section); the smooth trunkfish (triangular in cross-section but relatively small in size); the buffalo trunkfish (primarily triangular in cross-section, but shaped differently posteriorly, and large in size); and the cowfish (partially rectangular in cross-section, with a more ornamented surface). These studies will include flow visualization using 2-D and 3-D DPIV both around the body and in the wake; force balance estimations of lift and drag forces; and surface pressure distribution measurements for lift, drag, and boundary layer separation studies. Further work will also be done on fin performance using materials having different compliances. As time permits we will begin DPIV studies in water tunnels using living fishes, to start the process of integrating the properties of the fuselages of the animals with those of both their multiple propulsors and their respiratory movements. We plan to submit for publication at least two additional major data papers. We will also complete a second video summarizing aspects of the consequences of diversity in body shapes and sizes for flow regimes around the bodies of the fishes. We will also complete the organization of and raising funding to support a major, full day long, international symposium on "The dynamics and energetics of swimming and flying." This symposium will be presented at the January 2002 meeting of the Society for Integrative and Comparative Biology. Many ONR-supported scientists, in addition to our groups, have agreed to participate in this symposium.

Publications, Abstracts, Technical Reports, Patents & Awards:
Award:
The PI has been selected as the year 2000 Irving-Scholander Memorial Lecturer by the Institute of Arctic Biology and the Department of Biological Sciences, University of Alaska, Fairbanks, AK. He will present his lectures during September 2000. One of these lectures will be based upon the results of this project.
The complete citations for the papers mentioned above follow:

Papers submitted but not yet published:
Gordon, M.S., J.R. Hove, P.W. Webb, and D. Weihs. 2000. Boxfishes as unusually well controlled autonomous underwater vehicles. PHYSIOLOGICAL AND BIOCHEMICAL ZOOLOGY 73 (6): in press (November/December issue).

Hove, J.R., L.M. O'Bryan, M.S. Gordon, P.W. Webb, and D. Weihs. 2001. Boxfishes (Teleostei: Ostraciidae) as a model system for fishes swimming with many fins: I. Kinematics. JOURNAL OF EXPERIMENTAL BIOLOGY (submitted).

Papers published:

Hove, J.R., M.S. Gordon, P.W. Webb and D. Weihs. 2000. A modified Blazka-type respirometer for the study of swimming metabolism in fishes having deep, laterally compressed bodies or unusual locomotor modes. JOURNAL OF FISH BIOLOGY 56: 1017-1022.

Printed non-refereed papers:

Hove, J.R., M.S. Gordon, P.W. Webb, and D. Weihs. 1999. Boxfishes as a model system for fishes swimming with many fins. PROCEEDINGS 11TH INTERNATIONAL SYMPOSIUM ON UNMANNED UNTETHERED SUBMERSIBLE TECHNOLOGY, 5 pp.

Three papers will appear in the PROCEEDINGS OF THE 1ST INTERNATIONAL SYMPOSIUM ON AQUA BIO-MECHANISMS (ISABMEC 2000):

Gordon, M.S. and I.K. Bartol. Dynamic stability of swimming in boxfishes (Teleostei: Ostraciidae). 6 pp.

Lauritzen, D.V., F. Hertel, and M.S. Gordon. Biomechanics of salmonid fishes leaping up waterfalls. 2 pp.

Bartol, I.K. and M.R. Patterson. Swimming mechanics of squid and its applicability to the design of highly maneuverable autonomous underwater vehicles (AUVs). 6 pp.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02831**
Project Title:	**An Aerostat/Elevated Antenna Component to Aid VHF Radiotelemetry and Tracking of Right Whales in Critical Habitats**
Investigator(s):	**Hain, James H.W.**
Department or Division:	**Associated Scientists**
Performing Organization:	**Woods Hole Oceanographic Institution**
Geographic Location of Study:	**Coastal waters of SE US**
Marine Mammal Species Involved:	**Right whale**
FY 00 Funding Level:	**51,464**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

To evaluate and develop the use of an aerostat (tethered balloon) as an additional tool to aid in VHF radio tagging and data telemetry used to characterize endangered right whale habitat use, movements, and behavior, as well as to aid in the development of a more effective Early Warning System for mitigating human impacts in coastal waters of the southeastern US.

ANNUAL PROGRESS REPORT

Name: Hain

Grant Number: N00014-98-1-0853

Title: An aerostat/elevated antenna component to aid VHF radiotelemetry and tracking of right whales in critical habitats

Award Period: 15 August 1998 - 14 August 2000, extended to 14 August 2001

Objective:
To evaluate and develop the use of an aerostat (tethered balloon) as an additional tool to aid in VHF radio tagging and data telemetry used to characterize endangered right whale habitat use, movements, and behavior, as well as to aid in the development of a more effective Early Warning System for mitigating human impacts in coastal waters of the southeastern US.

Approach:
Phase I: 1) evaluate the logistics of aerostat deployment and aerostat-based antenna sites, 2) compare expected signal ranges to actual ranges, and 3) determine what steps would be required to further develop this research capability in both detecting and directionalizing a signal. Phase II: 1) incorporate improvements and refinements, 2) apply technology transfer where possible, and 3) move toward developing a multi-use capability.

Accomplishments:
During February 1999, initial field tests suggested improvements to the aerostat system. In the current reporting period, information was gathered and options developed for 1) rigorously evaluating aerostat performance in various wind and weather conditions, 2) using RF to uplink control functions and downlink data relay, 3) identifying an optimal winching system for deployment and recovery, and 4) developing additional capabilities for the system, including use as a photo and video platform.

Significance:
Two navy facilities are adjacent to the right whale calving and wintering grounds in the coastal waters of the southeastern U.S.: the submarine base at King's Bay Georgia, and the navy base at Mayport, Florida. The Navy has been an active and effective partner in right whale recovery and conservation efforts through its participation in the Coastal America Program, activities through the Legacy Program, through participation in the right whale Early Warning System, and through its support of research via the Office of Naval Research. In the past several years, the navy has established itself as a leader and a model for these types of efforts. In the last three years there have been no ship strikes on right whales in these waters.

There is also an important Technology Transfer aspect: The R&D achieved under this project (with both the deployment and use of aerostats, as well as the electronics involved with remote monitoring stations) will have wide application, not only to telemetry and monitoring of endangered large whales, but also to many other species. The aerostat is also envisioned as a multi-use platform, and can elevate antennas, cameras, and sensor packages. As part of the progressing development, we are currently interacting with investigators at Bosch Aerospace, Millersville University, Mote Marine Laboratory, Naval Surface Warfare Center, and the Woods Hole Oceanographic Institution.

This work is consistent with Navy interest in survey systems and technology for data collection in the littoral environment, offshore regions, and lower atmosphere.

Work Plan:

Under a 12-month extension (to 14 August 2001), an extensive program of field tests is planned for October 2000. The aerostat will be equipped with remote wind and weather monitoring sensors, and the tether equipped with a strain gauge. Data will be collected on aerostat performance, specifically lift and tether tension, vs. wind speed, air temperature, and humidity. Trials will also be conducted with various camera systems. At present, because of mixed results and recent concern about the impact of tagging on whales, no VHF tagging is being planned for 2000-2001 in SE US coastal waters. Therefore, while the use of the aerostat as an antenna platform will continue to be developed, we will also explore and develop multiple and alternate uses. The priority throughout will continue to contribute to monitoring and protection of right whales in and adjacent to the critical habitat in coastal waters of the southeast US.

Publications, Abstracts, Technical Reports, Patents & Awards:

Hain, J.H.W. 2000. Lighter-than-air platforms (blimps and aerostats) for oceanographic and atmospheric research and monitoring. Proceedings Oceans2000 conference, 11-14 September 2000, Providence, RI. 4 pp.

Hain, J.H.W. Shore-based tracking. Presentation to the Southeast US Implementation Team, Brunswick, GA, 5 May 2000.

Hain, J.H.W. Shore-based monitoring in the SEUS critical habitat. Presentation to Right Whale Consortium Meeting, Boston, MA. 22 October 1999.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00934**
Project Title:	**Undulatory Flap Propulsion – Reduction to Practice**
Investigator(s):	**Howle, Laurens E.**
Department or Division:	**Mechanical Engineering, Material Science**
Performing Organization:	**Duke University**
Geographic Location of Study:	**Durham, NC**
Marine Mammal Species Involved:	**N/A (modeling)**
FY 00 Funding Level:	**95,509**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Reduced-order computational methods are used to simulate and analyze propulsive motions used by biological swimmers such as Yellowfin Tuna. Particular attention is paid to the thrust generation and propulsive efficiency of these motions. The motions are adapted to Navy specific problems such as stealthy propulsion and high maneuverability in a turbulent environment. In adapting the biological propulsion principals to mechanical devices, the limitations of these mechanical devices and the quantitative consequences of these limitations are studied in detail. Through modeling, we distill the motions of biological swimmers into the simplest mechanical systems capable of reasonable propulsive performance.

ANNUAL PROGRESS REPORT

Name: Howle

Grant Number: N00014-99-1-0452

Title: Undulatory Flap Propulsion – Reduction to Practice

Award Period: 01 May 1999 – 30 April 2002

Approach:
Reduced-order computational methods are used to simulate and analyze propulsive motions used by biological swimmers such as Yellowfin Tuna. Particular attention is paid to the thrust generation and propulsive efficiency of these motions. The motions are adapted to Navy specific problems such as stealthy propulsion and high maneuverability in a turbulent environment. In adapting the biological propulsion principals to mechanical devices, the limitations of these mechanical devices and the quantitative consequences of these limitations are studied in detail. Through modeling, we distill the motions of biological swimmers into the simplest mechanical systems capable of reasonable propulsive performance.

Accomplishments:
We have completed i) an automated digital image analysis program to locate and track, in time and space, the backbone location of swimming fish. This program will save man-months of effort by our collaborators in the coming year. These data are used as input to our numerical model that analyzes the propulsive parameters (thrust, vortex sheet evolution, propulsive efficiency) of the swimming fish. We have completed computer models that ii) simulate swimming motions for a variety of commonly used fish waveforms, iii) simulate and analyze fluid-structure interaction from vortex sheet capture and manipulation, iv) simulate and analyze general propulsive motions of flexible three-dimensional propulsors. Additionally, we have v) conducted wind tunnel measurements of lift and drag from our flexible propulsors (developed with Nekton Technologies, Inc.) that are used to propel and maneuver an unmanned underwater vehicle. Items i and ii tie into the basic research component of this project while items iii-v fuel the technology development portion of this work.

Significance:
The basic research portion of this work will improve the understanding of underwater biological propulsion. The technology development portion of this work will use this information to develop novel propulsion systems for Navy-specific needs.

Work Plan:
- Extend the capabilities of our digital imaging program to include analytical capabilities such as automated function fitting through multi-dimensional least squares minimization.

- Use homogenization theory to develop an analytical model of vertebral flexure during swimming – this will provide a more accurate model than the simplified beam equation used by many researchers.
- Develop and begin measurements of fish geometry (external) using an automated ultrasonic measurement tank. An accurate description of the external geometry of fish body and fins is needed for our next generation of numerical modeling.
- Begin simulation of swimming fishes using vortex ring method that allow the three-dimensional potential flow problem to be solved for the computational cost of a two-dimensional problem.
- Develop a parabolized Navier-Stokes boundary layer solver to link to our potential flow programs so that we can simulate viscous forces during swimming/propulsion.
- Critically and quantitatively analyze the "added mass" effects present during swimming and thrust production by oscillatory actuation
- Begin testing mechanical swimmers at the facilities of the Unites States Naval Academy (contact: Mark M. Murray).

Publications, Abstracts, Technical Reports, Patents & Awards:

Publications

1. Murray, M.M. & Howle, L. E. (2000). "Spring Stiffness Influence on an Oscillating Propulsor". Submitted to *Journal of Fluids and Structures*.
2. Murray, M.M. (2000). *Hydroelasticity Modeling of Flexible Propulsors*. Ph.D. Dissertation. Duke University. Durham, NC.
3. Howle, L.E. (1999). "Undulatory Flap Propulsion". *11th International Symposium on Unmanned Untethered Submersible Technology*. pp. 487-493.
4. Howle, L.E. (1999). "Undulatory Flap Pair Propulsion". *Bulletin of the American Physical Society. Program of the 52nd annual meeting of the Division of Fluid Dynamics*. **44**:178.
5. Murray, M.M. & Howle, L.E. "Translational Spring Stiffness Influence on an Oscillating Propulsor". *Bulletin of the American Physical Society. Program of the 52nd annual meeting of the Division of Fluid Dynamics*. **44**:178.

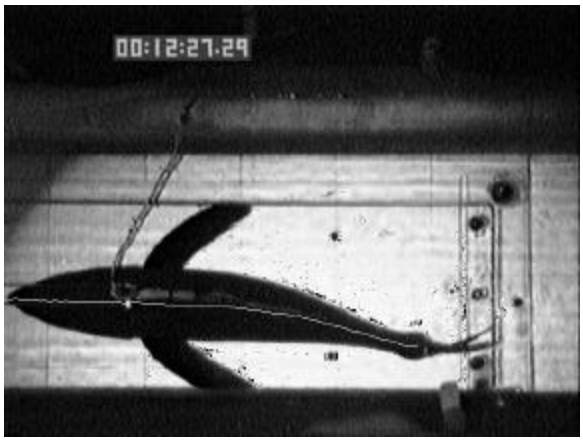
Presentations

1. Howle, L.E. *Undulatory Flap Propulsion*. 11th International Symposium on Unmanned Untethered Submersible Technology. Durham, New Hampshire. 25 August, 1999.
2. Howle, L. E. *Undulatory Flap Pair Propulsion*. American Physical Society Division of Fluid Dynamics Meeting, New Orleans, Louisiana. 23 November, 1999.
3. Murray, M.M. *Hydroelasticity Modeling of Flexible Propulsors.* American Physical Society Division of Fluid Dynamics Meeting, New Orleans, Louisiana. 23 November, 1999.

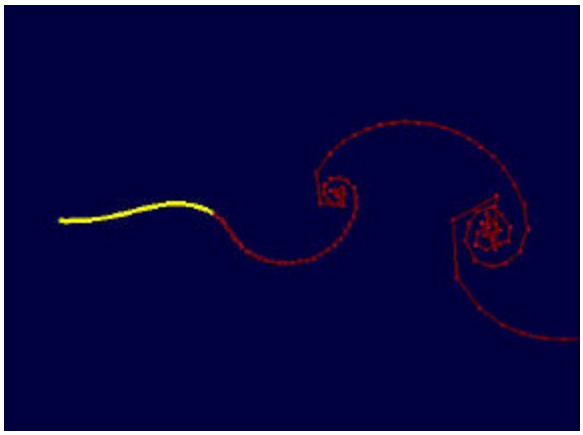
Promotions

1. Howle, L.E. to Associate Professor (with tenure) of Mechanical Engineering and Materials Science.

2. Murray, M.M. selected for promotion to Commander U.S. Naval Reserve, Recall to active duty effective 8/1/00 as Instructor, United States Naval Academy.



This image shows the output from an automated digital image processing program. The program was written by Laurens Howle and the image supplied by Steve Katz. This program automates the process of finding the fish midline (approximate backbone position) for a movie or series of still images. In this case, we use images of a swimming Yellowfin Tuna. The midline is shown as the white line in this figure. The data gathered from this program are used to analyze the biofluiddynamics of swimming fish. For example, the muscle strain history of this fish is deduced from the phase velocity and extrema of curvature of this midline. Additionally, movement of the midline is used to analyze the hydrodynamics of swimming.



This image shows a snapshot of a swimming plate (yellow) and the resulting unsteady shed vortex pattern (red). We use the midline data gathered from digitally processed images of swimming fish (slide 3) to prescribe the plate motion. From the analysis of the vortex motion, we measure thrust production and propulsive efficiency. This information serves as the foundation of our biomimeticdesigns of undulatory propulsors.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**99PR06285**
Project Title:	**Effects of low frequency sound on ringed seal navigation and behavior in their sub-ice habitat**
Investigator(s):	**Kelly, Brendan P.**
Department or Division:	**Juneau Center, School of Fisheries and Ocean Sciences**
Performing Organization:	**University of Alaska, Fairbanks**
Geographic Location of Study:	**Beaufort Sea**
Marine Mammal Species Involved:	**Ringed seals**
FY 00 Funding Level:	**40,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The three-dimensional movements of free-ranging ringed seals swimming under shore-fast sea ice were tracked acoustically. Behavioral responses to playbacks of 850 Hz tones were recorded and received levels were calculated based on the distance between a seal and the source. The importance of audition in underwater navigation was tested for seals swimming with full vision and for seals swimming blindfolded under the ice.

ANNUAL PROGRESS REPORT

Name: Kelly

Grant Number: N00014-95-1-0383

Title: Effects of low frequency sound on ringed seal navigation and behavior in their sub-ice habitat

Award Period: 15 January 1995 – 30 September 2000

Objective:
To determine the effects of low frequency sound on the normal activity patterns of ringed seals (*Phoca hispida*).

Approach:
The three-dimensional movements of free-ranging ringed seals swimming under shore-fast sea ice were tracked acoustically. Behavioral responses to playbacks of 850 Hz tones were recorded and received levels were calculated based on the distance between a seal and the source. The importance of audition in underwater navigation was tested for seals swimming with full vision and for seals swimming blindfolded under the ice.

Accomplishments:
We captured and radio-tracked 10 ringed seals in April – June 2000. Six of those seals were also acoustically tracked under the ice. After determining a seal's under-ice home range, he was recaptured and fitted with a blindfold. The seal's subsequent under-ice movements were recorded in the presence and absence of acoustic cues.

Significance:
This study will provide information about the under water use of sound by phocids generally and ringed seals in particular. That information is necessary in order to make meaningful predictions about impacts of man-made sounds, including low frequency sounds, on seals.

Work Plan:
Data collection is completed and most of the analyzes have been completed. Three manuscripts have been prepared and will be submitted to Animal Behaviour, Marine Mammal Science, and the Canadian Journal of Zoology. In the next few months, we intent to complete and report on the analysis of our final field experiments and prepare a proposal to extend those results with additional field experiments.

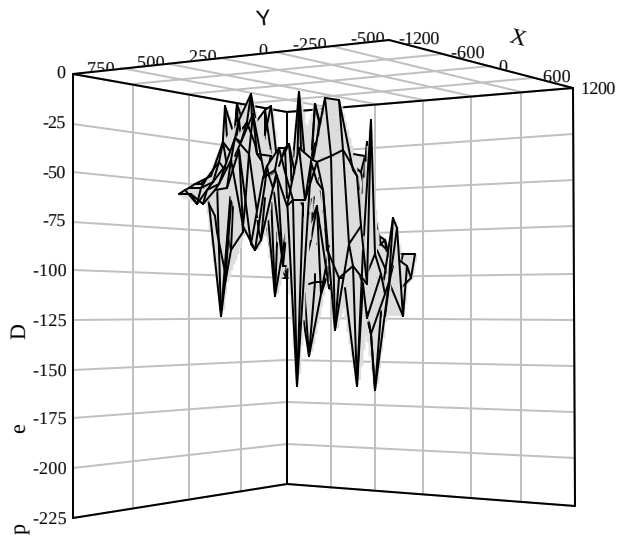
Publications, Abstracts, Technical Reports, Patents & Awards:
Simpkins, M. A., B. P. Kelly, and D. Wartzok. 1999. Three-dimensional analysis of search behavior by ringed seals. 13th Biennial Conference on the Biology of Marine Mammals. Nov. 28 – Dec. 3, 1999. Wailea, Maui, Hawaii. (Abstract).

Simpkins, M. A. 2000. Three-dimensional diving behavior of ringed seals. Ph.D. thesis. University of Alaska Fairbanks.

Simpkins, M. A., B. P. Kelly, and D. Wartzok. *in prep*. Analysis of three-dimensional search behavior by ringed seals. To be submitted to Animal Behaviour.

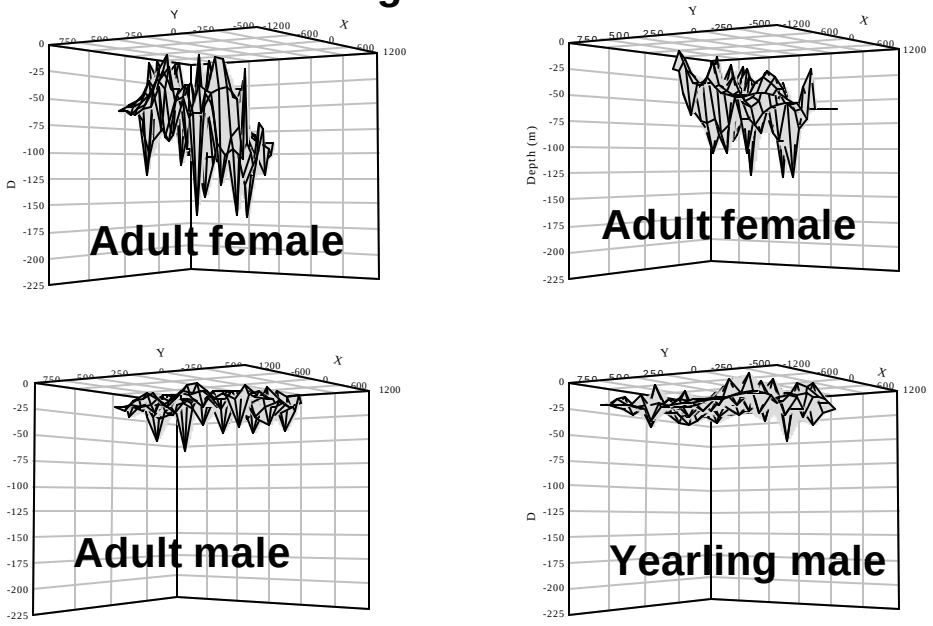
Simpkins, M. A., B. P. Kelly, and D. Wartzok. *in prep*. Definition of three-dimensional diving behaviors exhibited by ringed seals. To be submitted to Marine Mammal Science.

Simpkins, M. A., B. P. Kelly, and D. Wartzok. *in prep*. Three-dimensional movement behavior within individual dives of ringed seals. To be submitted to Canadian Journal of Zoology.



This graph shows the three-dimensional sub-ice home range of a female ringed seal determined by acoustic tracking.

Tracking: natural conditions



Three-dimensional home ranges

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR04767**
Project Title:	**VHF Radiotelemetery tracking of right whales in SE U.S. Coastal Waters**
Investigator(s):	**Kraus, Scott and Chris Slay**
Department or Division:	**N/A**
Performing Organization:	**New England Aquarium**
Geographic Location of Study:	**Southeastern US coastal waters**
Marine Mammal Species Involved:	**Northern Right whale**
FY 00 Funding Level:	**59,829**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

A VHF-transmitter was implanted into the blubber layer of a northern right whale cow in the calving ground off the coast of north Florida on 01/20/99. The whale and her calf were tracked continuously for 44 hours before bad weather interrupted tracking. Tracking was resumed on 01/25/99 for 96 continuous hours. Tracking was conducted from a 20 meter research vessel fitted with a flying bridge for behavioral observation and a VHF-radio receiving system of four antennas, oriented 90 degrees apart, which sent signals to an Automatic Direction Finding unit (ADF). The ADF not only provided directionality but also a measure of relative received signal strength, which was equated with distance from the vessel during daytime observations, and allowed the vessel crew to estimate distance to the whale during nighttime. Each surfacing and dive as inferred from the received radio signals were logged on a notebook computer running a data-logging program.

ANNUAL REPORT REPORT

Name: Kraus, Slay

Grant Number: N00014-98-1-0852

Title: VHF Radiotelemetery tracking of right whales in SE U.S. Coastal Waters (yr 2)

Award Period: 15 August 1998 – 30 September 2000

Objective:
To use VHF-radio transmitters to document fine-scale movement, swim-speed, diurnal surface/dive patterns and behaviors of northern right whale cows with a calves in the right whale calving ground; to use these data to assess current efforts to reduce right whale mortality in the calving ground.

Approach:
A VHF-transmitter was implanted into the blubber layer of a northern right whale cow in the calving ground off the coast of north Florida on 01/20/99. The whale and her calf were tracked continuously for 44 hours before bad weather interrupted tracking. Tracking was resumed on 01/25/99 for 96 continuous hours. Tracking was conducted from a 20 meter research vessel fitted with a flying bridge for behavioral observation and a VHF-radio receiving system of four antennas, oriented 90 degrees apart, which sent signals to an Automatic Direction Finding unit (ADF). The ADF not only provided directionality but also a measure of relative received signal strength, which was equated with distance from the vessel during daytime observations, and allowed the vessel crew to estimate distance to the whale during nighttime. Each surfacing and dive as inferred from the received radio signals were logged on a notebook computer running a data-logging program.

Accomplishments:
A total of 132 hours of surface and dive behavior were monitored from the radio tag signals during two tracking episodes. There were 827 surface and dive intervals recorded for the tagged whale. Visual observations during daylight hours confirmed that patterns of surfacings and dives less than 1 minute were the result of the whale bobbing at the water's surface and submerging the radio-tag's antenna. Means for surface and dives of < 1 minute were combined with surface intervals of > 1 minute, yielding a mean for surface intervals of 5.6 minutes. Mean for dive intervals > 1 minute was 7 minutes. This suggests #1612 spent 45% of the time at the surface and 55% submerged. There was no significant difference in surface dive behavior for day and night periods. The whale and her calf averaged 1.04 knots over the course of this study. Mean day and night swim speeds were nearly identical. Distance covered in a single 24-hour day/night period ranged from 19NM – 29NM. Average: 24.6 nautical miles. The greatest distance the pair covered during a 24-hour period was 29 NM. Over 73% of the whales' movement was in

water <25 meters deep and for several hours the pair were in water warmer than 20 degrees C.

Tagging and tracking systems developed during this contract enabled the tagging of an entangled right whale in August of 1999. This whale was tracked and subsequently disentangled, likely saving its life.

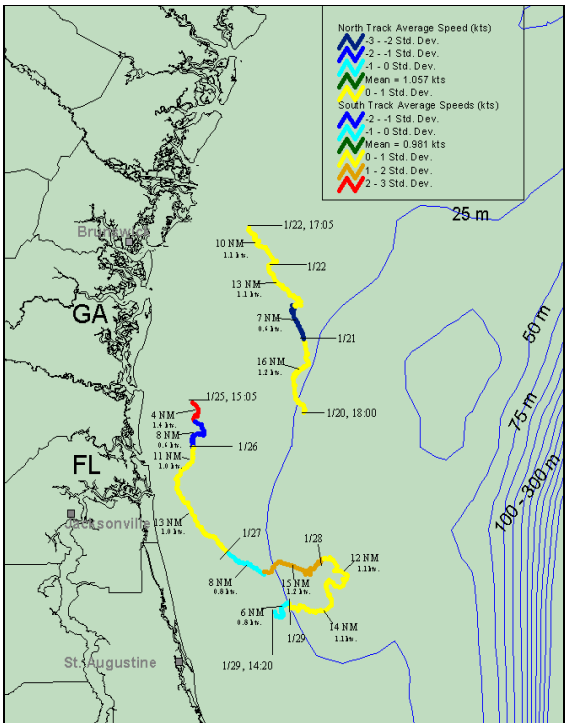
Significance:
At present, the primary strategy for reducing right whale mortality in the calving ground relies on locating whales by aerial surveys and alerting the operators of large vessels to their presence. The only published study concerning sightability of right whales in the calving ground (Hain, et al 1999), found the mean surface time for mothers was 54% based on 11 hours visual observation from an airship and concluded that 33% of the mother/calf right whales would be sighted by surveys when conditions were favorable (good visibility, Beaufort <4). The results of 132 hours of VHF-tracking (mean surface time: 45%) suggest that the sightability of mother/calf pairs in the calving ground may be even lower than previously thought.

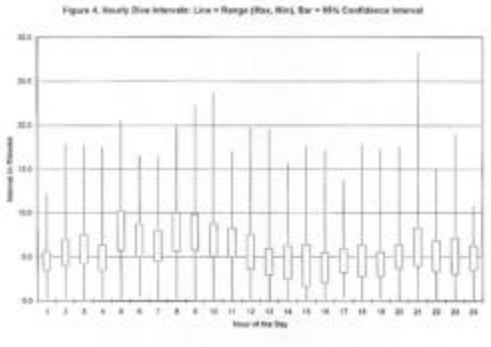
The most proactive protocol for the operation of large vessels in the calving ground requires that sea-going dredges, contracted by the Navy and the U.S. Army Corps of Engineers, reduce speed during nighttime or limited visibility for 24-hours following any right whale sighting within 15 NM of the dredging operations. The Navy has indicated a willingness to modify operations of vessels at the Kings Bay Naval Base if whales are present in the channel and will take precautionary measures if whales have been sighted within 10 NM of their area of operations during the previous 24-hours. Effectiveness of such measures is linked to the distance a right whale can travel in a 24-hour period. The VHF-tracking demonstrates that a cow/calf pairs travel 29 NM in 24- hours. This work underscores the limitations of current mitigation strategies. The sightability and rate of movement of right whales must be taken into account when developing future management protocols for reducing right whale mortality associated with shipping in the calving ground.

Tagging and tracking technology developed under this contract is an important component of current efforts to disentangle right whales ensnared in fishing gear.

Work Plan:
During the second year of this contract no whales were tagged. There was only one right whale cow/calf pair documented in the calving ground during 2000, despite a record level of aerial survey effort. This was the worst year on record for calving in this population. The development of tracking systems was continued and substantially improved as evidenced in extensive testing. Assistance from ONR, NMFS and the International Fund for Animal Welfare (IFAW) was crucial to this progress. Our data logging capability and tracking range was significantly increased and a video tracking system was developed to get exact range and bearing data during daylight observations. Unfortunately, the opportunity to make use of these developments never materialized.

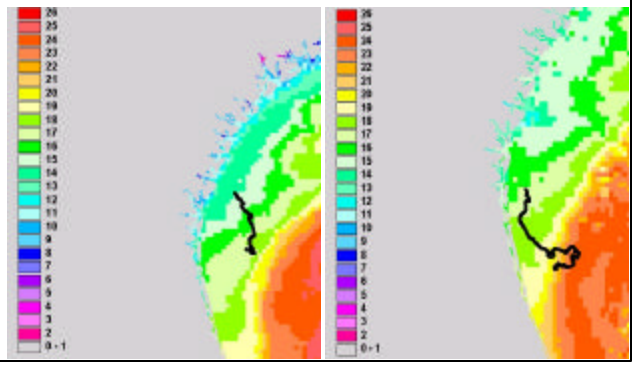
ONR has agreed to allow the use of funding, not spent on boat time for tracking, to be directed at the development of a tethered tagging system similar to those being used on large pelagic fish. Success tracking bluefin tuna has been achieved by researchers at the New England Aquarium. If such a system can be adapted to large whales it will increase the variety of long-term remote sensing devices that can be used on large cetaceans.





Corrected mean was 5.6 minutes for surface intervals and 7 minutes for dive intervals. This pair was available to be detected at the surface 45% of the time. There was no significant difference in surface and dive intervals for day and night periods.

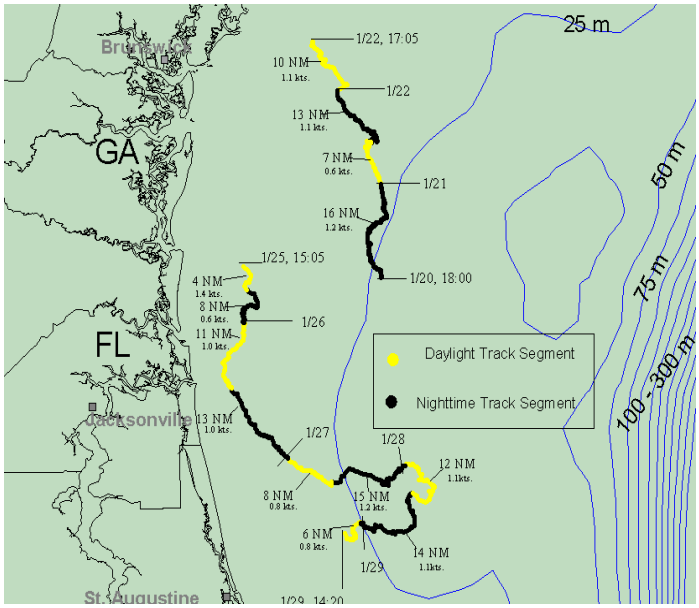
The cow/calf pair moved from 14 degree C water to 24 C water during tracking. The Navy uses 20 C as one parameter for the likelihood of presence or absence of right whales in this region.



Distance covered in a single day /night period ranged from 19NM (nautical miles) to 29NM. Average: 24.6 NM.

The best of current protocols assume movements of detected whales to be less than 15 NM in than in 24 hours.

Over 73% of the whales track is in water <25 meter deep-- not much of an escape route from deep draft vessels.



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR05880**
Project Title:	**The Ontogeny of the Dolphin Echolocation System**
Investigator(s):	**Kuczaj, Stan**
Department or Division:	**Psychology Department**
Performing Organization:	**University of Southern Mississippi**
Geographic Location of Study:	**San Diego, CA**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**251,040**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Objective is to obtain an enhanced understanding of how dolphin sonar works by studying its development in young animals.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR08059**
Project Title:	**A Satellite Imagery, Ecosystem-based GIS study of Bluefin Tuna and Right Whale Distribution and Movements in the Gulf of Maine and NW Atlantic.**
Investigator(s):	**Lutcavage, Molly and Scott Kraus**
Department or Division:	**N/A**
Performing Organization:	**New England Aquarium**
Geographic Location of Study:	**Gulf of Maine, Northwest Atlantic**
Marine Mammal Species Involved:	**Right whales, Bluefin tuna**
FY 00 Funding Level:	**100,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The New England Aquarium's Edgerton Research Laboratory has undertaken research efforts to examine the distribution and abundance of bluefin tuna and right whales using a variety of research platforms. The addition of satellite telemetry has enabled us to look at multi-scale movements of these animals. However, the scale at which the animals interact with their heterogeneous seascapes necessitates the use of GIS and spatial analysis. We are examining animal movements in relation to several static and dynamic environmental variables, including sea surface temperature (AVHRR), sea surface height (TOPEX/Poseidon), ocean color (SeaWiFs), ocean depth, prey species distribution (copepod abundance), and interpolated variables (e.g., slope and animal density). These data will then be analyzed using multivariate and spatial statistics, such as NMDS and Mantel test.

ANNUAL PROGRESS REPORT

Name: Lutcavage, Kraus

Grant Number: N00014-99-1-1035

Title: A Satellite Imagery, Ecosystem-based GIS study of Bluefin Tuna and Right Whale Distribution and Movements in the Gulf of Maine and NW Atlantic.

Award Period: 1 September 2000 – 31 August 2001

Objective:
Through the use of available in situ and remotely sensed oceanographic data, we are attempting to examine the species-environment relationship for bluefin tuna and northern right whales.

Approach:
The New England Aquarium's Edgerton Research Laboratory has undertaken research efforts to examine the distribution and abundance of bluefin tuna and right whales using a variety of research platforms. The addition of satellite telemetry has enabled us to look at multi-scale movements of these animals. However, the scale at which the animals interact with their heterogeneous seascapes necessitates the use of GIS and spatial analysis. We are examining animal movements in relation to several static and dynamic environmental variables, including sea surface temperature (AVHRR), sea surface height (TOPEX/Poseidon), ocean color (SeaWiFs), ocean depth, prey species distribution (copepod abundance), and interpolated variables (e.g., slope and animal density). These data will then be analyzed using multivariate and spatial statistics, such as NMDS and Mantel test.

Accomplishments:
Since January we have set up a GIS lab consisting of an NT and a Linux workstation. We posted a website in late March that outlined our research goals within the context of the ONR grant. This website (www.marinegis.org) highlights the two focal species, the environment, and the kinds of scientific questions of interest. Since that time, we have been busy constructing the geo-spatial database necessary for this work. This has involved creating numerous data layers of distribution, abundance and movements of tuna and whales, as well as supporting data layers including ocean depth and bottom topography. For the RS data, we have constructed GIS coverages for the TOPEX/Poseiden data, but are awaiting geo-referenced AVHRR data from the Northeast NMFS Node. We are currently in the process of obtaining and geo-referencing sea surface temperature front data from University of Rhode Island's Distributed Oceanographic Dataset system.

Significance:
Understanding animal distribution and abundance patterns in relation to their environment have long been a fundamental goal of ecology. The application of this research paradigm to marine environments remains in early stages, but for the two focal species of this grant it is of paramount importance. Northern Right Whales remain one of the planet's most critically endangered species. Teasing out spatially and temporally specific responses to the dynamic environment will greatly enhance our understanding of the life history patterns for both species, and will offer researchers and managers the tools to make better decisions about the Gulf of Maine ecosystem and its inhabitants.

Work Plan:
The construction of the environmental data layers remains an intensive process in the marine environment. For example, for one right whale tagged in the Gulf of Maine in the fall of 1997, we will use GIS to sample over 50 data layers. We will continue to complete the environmental database for bluefin tuna seen during aerial surveys from 1993-1996 in the Gulf of Maine, as well as for tuna tagged with popup satellite tags. The right whale data will be analyzed for two different databases as well: three satellite tagged whales in the Gulf of Maine, and whales seen in the Gulf of Maine from research vessel surveys conducted by NEAq. When the datalayers are complete for the relevant time frames we will conduct statistical analysis to attempt to develop a better understanding of right whale and bluefin tuna distribution and abundance in response to a shifting environment. The results of these efforts will be published in peer-reviewed journals, and will be made available on our website.

Publications, Abstracts, Technical Reports, Patents & Awards:
None- we are in the first year of the program.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01656**
Project Title:	**Right Whale Habitat and Migration in the North Atlantic Ocean**
Investigator(s):	**Mate, Bruce**
Department or Division:	**Hatfield Marine Science Center**
Performing Organization:	**Oregon State University**
Geographic Location of Study:	**North Atlantic Ocean**
Marine Mammal Species Involved:	**Right whale**
FY 00 Funding Level:	**136,967**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

(1) Characterize oceanographic habitat of feeding right whales; (2) describe diving and foraging behavior; (3) document fall migration and winter habitat of non-calving right whales; (4) better identify winter calving habitat; and (5) identify spring migration of "Bay of Fundy - none" whales to their summer feeding habitats.

ANNUAL PROGRESS REPORT

Name: Mate

Grant Number: N00014-00-1-0085

Title: Right Whale Habitat and Migration in the North Atlantic Ocean

Award Period: 15 October 1999 - 30 September 2002

Objective:
(1) Characterize oceanographic habitat of feeding right whales; (2) describe diving and foraging behavior; (3) document fall migration and winter habitat of non-calving right whales; (4) better identify winter calving habitat; and (5) identify spring migration of "Bay of Fundy - none" whales to their summer feeding habitats.

Approach:
(1) Semi-implantable Argos (satellite-monitored) radio tags will be used to track whales and identify feeding, calving, and migration habitats (objective numbers 1, 3, 4 and 5); (2) short-term suction cup attachments will be used for time-depth recorders (TDR) to examine the dive depths of feeding right whales while oceanographic data is collected from NOAA vessels (optical plankton counter, CTD, and net tows to determine plankton species, depth, and concentration); and (3) satellite images for sea surface temperature (AVHRR) and primary productivity (SeaWifs) will be analyzed to characterize high use right whale habitats.

Accomplishments:
(1) Data collected during a NOAA cruise in August 1999 indicate higher abundances of copepods in the presence of whales versus those sites without whales; (2) Permits and logistics are in place for tagging and oceanographic data collection for two NOAA cruises (July and August); (3) recoverable time depth recorders which incorporate flashing lights and VHF transmitters have been developed; and (4) Argos transmitters and Argos ADF and appropriate software are prepared for upcoming cruises.

Significance:
The completion of this project should characterize right whale feeding habitats and migratory corridors. These data may suggest how changes in fishing and shipping could reduce right whale mortalities.

Work Plan:
Two cruises (July and August) on NOAA vessels in the Bay of Fundy and along the Scotian Shelf will collect oceanographic data and provide access to whales for tagging with satellite-monitored radio tags and TDRs. Analyses of plankton samples will begin immediately. Satellite images will be collected during the recovery of Argos-based data (possibly 8-12 months duration) and be analyzed as a unit. Photographs of tagged whales

collected during the two cruises and from other right whale researchers will be examined for evaluation of possible tag effects. Planning will be undertaken for tagging in the winter calving range during winter 2001.

Publications, Abstracts, Technical Reports, Patents & Awards:

Publications:

Lagerquist, B. A., K. M. Stafford and B. R. Mate, 2000. Dive characteristics of satellite-monitored blue whales (*Balaenoptera musculus*) off the Central California coast. Marine Mammal Science 16(2):375-391.

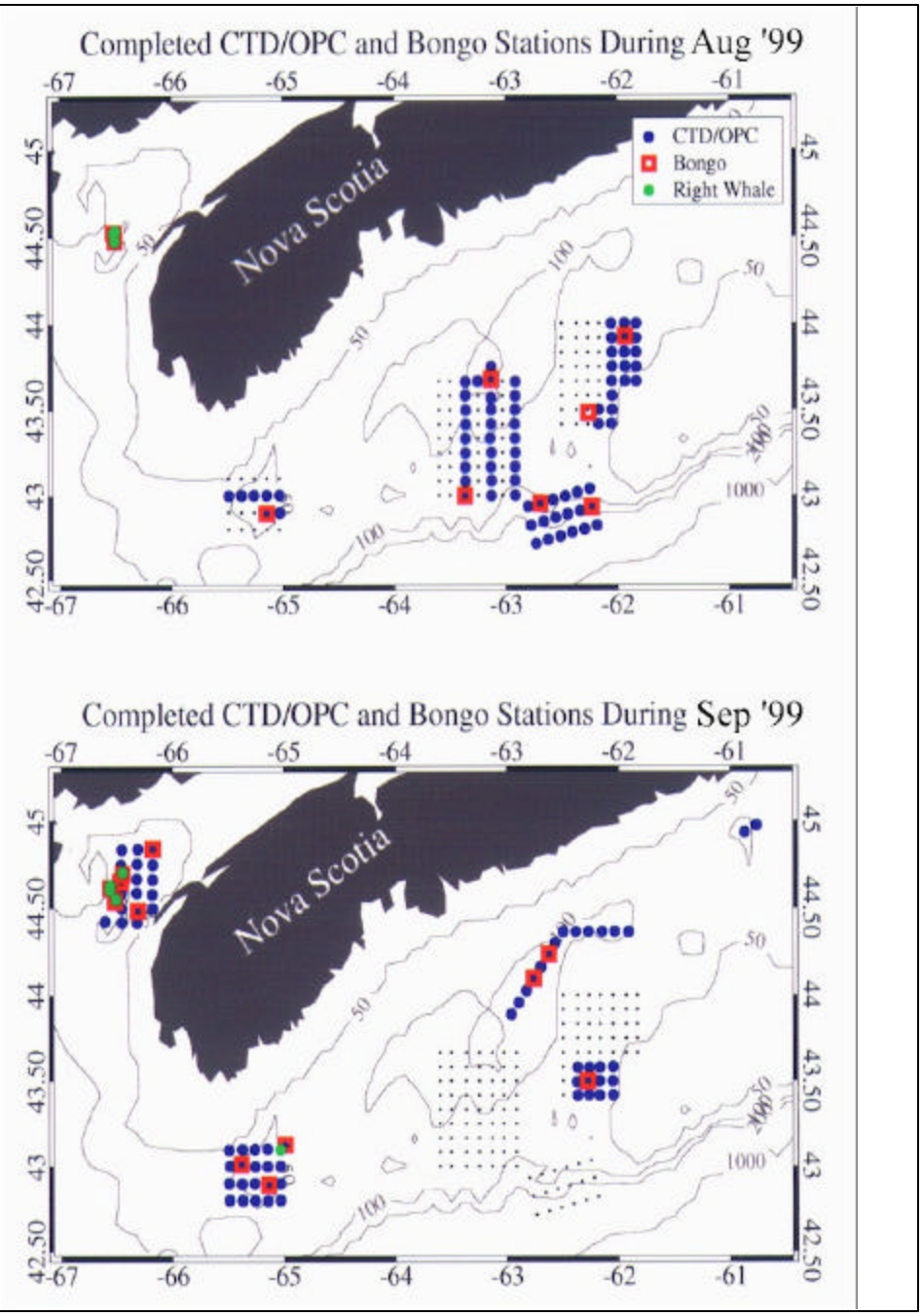
Mate, B. R. and B. A. Lagerquist, 1999. Movements of North Pacific blue whales during the feeding season off southern California and their southern fall migration. Marine Mammal Science 15(4):1246-1257.

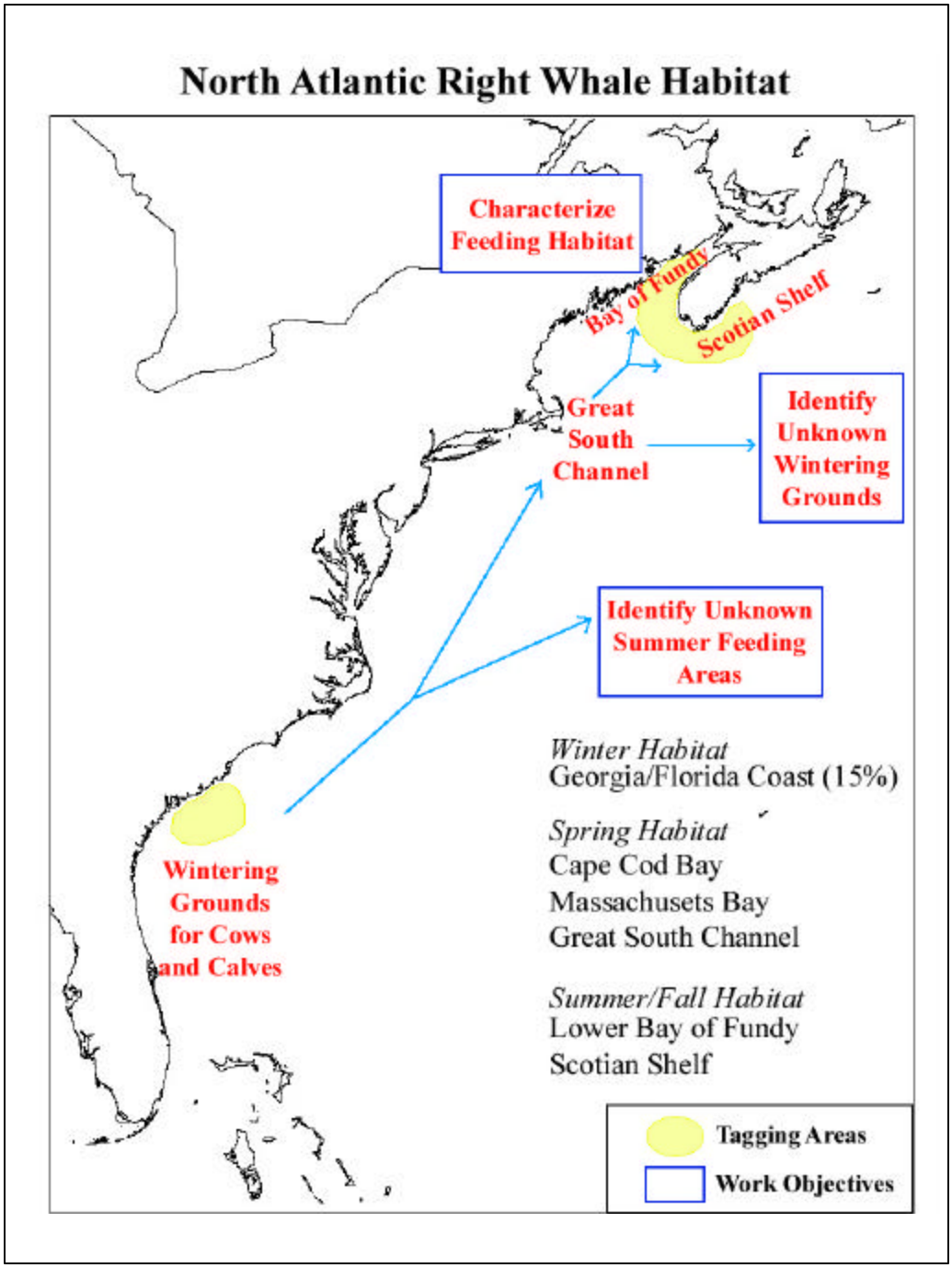
Presentations:

Mate, B.R. 2000. Fall migration and winter range of blue whales in Mexican waters. SOMEMMA (Sociedad Mexicana para el estudio de los mamiferos marinos). March 1999.

Mate, B. R. 2000. Critical habitats of blue whales in the eastern North Pacific. 14th Annual conference of the European Cetacean Society 2-5 April 2000, Cork, Ireland.

Mate, B.R. 1999. North Pacific humpback whales: winter movements around Hawaii, northward migratory routes and summer. Invited plenary speaker. Society for Marine Mammalogy, November 28-December 3, 1999. Wailea, Maui, Hawaii.


Completed CTD/OPC and Bongo Stations During Aug '99
CTD/OPC
Bongo
Right Whale
Nova Scotia
-67
-66
-65
-64
-63
-62
-61
45
44.50
44
43.50
43
42.50
50
100
1000
Completed CTD/OPC and Bongo Stations During Sep '99
Nova Scotia


North Atlantic Right Whale Habitat
Characterize Feeding Habitat
Bay of Fundy
Scotian Shelf
Great South Channel
Identify Unknown Wintering Grounds
Identify Unknown Summer Feeding Areas
Wintering Grounds for Cows and Calves
Winter Habitat
Georgia/Florida Coast (15%)
Spring Habitat
Cape Cod Bay
Massachusets Bay
Great South Channel
Summer/Fall Habitat
Lower Bay of Fundy
Scotian Shelf
Tagging Areas
Work Objectives

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR08058**
Project Title:	**Broadband, Broadbeam, Biomimetic Minehunting Principles**
Investigator(s):	**McDonald, Robert J**
Department or Division:	**R12**
Performing Organization:	**Coastal Systems Station, Panama City**
Geographic Location of Study:	**Panama City, Florida**
Marine Mammal Species Involved:	**Dolphin**
FY 00 Funding Level:	**63,938**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

A prototype broadband sonar with transmit power, beamwidth and bandwidth parameters such that dolphin echolocation trains may be transmitted and received with sufficient fidelity will be used to collect the broadband database. An assessment of the existing wideband sonar technology was made prior to developing a comprehensive sonar specification and associated statement of work (SOW). The results of this technology assessment study indicate that a broadband sonar operating in a band from 30 kHz to 110 kHz, with a source level of 209 dB re 1uPa at 1 meter, and receive and transmit beam patterns approximating those of a dolphin, would be considered a high risk effort.

ANNUAL PROGRESS REPORT

Name: McDonald

Grant Number: N0001499WX30286

Title: Broadband, Broadbeam, Biomimetic Minehunting Principles

Award Period: 01 June 1999 – 31 May 2000

Objective:
The objective of this project calls for the collection of a realistic robust broadband data set obtained at sea via a prototype broadband sonar capable of closely emulating dolphin echolocation signals. This data set will subsequently be used in the evaluation and refinement of ONR sponsored detection/classification algorithms for the determination of an optimally fused classification algorithm.

Approach:
A prototype broadband sonar with transmit power, beamwidth and bandwidth parameters such that dolphin echolocation trains may be transmitted and received with sufficient fidelity will be used to collect the broadband database. An assessment of the existing wideband sonar technology was made prior to developing a comprehensive sonar specification and associated statement of work (SOW). The results of this technology assessment study indicate that a broadband sonar operating in a band from 30 kHz to 110 kHz, with a source level of 209 dB re 1uPa at 1 meter, and receive and transmit beam patterns approximating those of a dolphin, would be considered a high risk effort.

A variety of classification algorithms will be evaluated. These include, Subband Decomposition by Wavelet Packets, Filter-Bank Classifier, Matched Filter/SCAT Based Classification, Best Discriminating Basis Classifier, and the Integrator Gateway Neural Network Classifier, as well those which employ time-frequency techniques on biomimetic transmit signals. In addition, the recent work involving principal component analysis in the wavelet domain by Moons and Okimoto of Oricon has yielded excellent results on the 80kHz bandwidth CSS LFM2 data set.

Accomplishments:
Based on an assessment of broadband sonar transducer technology by Presearch, a specification and statement of work for the construction of a wide bandwidth sonar was written in accordance with standard government contracting procedures. Contractor proposals responding to the request for proposals for the construction of the specified wide bandwidth sonar were evaluated and subsequently rejected on technical merit considerations. The specification for the wide bandwidth sonar was revised so as to induce a response from other industrial contractors.

A procedure for modeling the channel impulse response as a tapped delay line with time varying weights was developed. An adaptive technique to calculate the time varying tap weights was also designed. This work will permit one to ascertain the validity of the linear time invariant (LTI) assumption when filtering the acoustic returns.

A complete sea test plan was devised for the out year data collection effort. The plan included the design of specific signals for analyzing the channel impulse response, as well as signals for algorithm evaluation. Layout of the test field and target types was done to maximize the effectiveness of the database for the algorithm evaluation efforts.

Significance:
The broadband data collected will be archived in the Naval Sensor Database to be made available to other researchers. Hence, this work will have application on the development of future broadband MCM sonar systems and on the continued development and refinement of detection and classification algorithms.

Work Plan:
We expect to receive and evaluate several high quality proposals for the broadband sonar. The contract for sonar construction is expected to be let by Sept. 30, 2000. Construction is expected to take 12 months from the time the contract is let.

Publications, Abstracts, Technical Reports, Patents & Awards:
none

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR07202**
Project Title:	**Lower Trophic Level Oceanographic Measurements for SOLMR**
Investigator(s):	**McGehee, Duncan E.**
Department or Division:	**Analysis & Applied Research**
Performing Organization:	**BAE Systems**
Geographic Location of Study:	**Mediterranean Sea**
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**100,199**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

This work is being done in support of the Sound, Oceanography, and Living Marine Resources (SOLMR) program, a program spearheaded by the NATO SACLANT Centre to develop ways of mitigating risks to whales from anthropogenic sound sources. The study in 1999 was conducted in the Ligurian Sea north of Corsica. The purpose of the work reported here was to map physical oceanographic parameters and distributions of phytoplankton and zooplankton during the period of the field study as a possible way of explaining and predicting the distribution of fin and sperm whales.

ANNUAL PROGRESS REPORT

Name: McGehee

Grant Number: N00014-99-C-0317

Title: Lower Trophic Level Oceanographic Measurements for SOLMR

Award Period: 13 August 1999 – 13 August 2001

Objective:
This work is being done in support of the Sound, Oceanography, and Living Marine Resources (SOLMR) program, a program spearheaded by the NATO SACLANT Centre to develop ways of mitigating risks to whales from anthropogenic sound sources. The study in 1999 was conducted in the Ligurian Sea north of Corsica. The purpose of the work reported here was to map physical oceanographic parameters and distributions of phytoplankton and zooplankton during the period of the field study as a possible way of explaining and predicting the distribution of fin and sperm whales.

Approach:
The lower trophic level study was done on the Italian Naval Hydrographic Vessel *Ammiraglio Magnaghi*, 2-13 August, 1999. Basic physical measurements were made using a CTD and estimates of phytoplankton abundance were made using a fluorometer. Small zooplankton (e.g. copepods and smaller) measurements were made acoustically using a TAPS (Tracor Acoustic Profiling System), supplemented by periodic vertical net hauls using a 0.5 m plankton net. In addition, Dave Demer from the Southwest Fisheries Science Center participated in the cruise and provided underway measurements of large zooplankton (e.g. euphausiids and larger) using an EK500 scientific echosounder.

Accomplishments:
The distributions of temperature, salinity, chlorophyll and zooplankton were intended to provide a backdrop on which to explain August whale distributions in the Ligurian Sea. The physical measurements supported the notion of a counterclockwise circulation in the Ligurian Sea, leading to upwelling in the center. The chlorophyll measurements indicated higher phytoplankton abundance in the center of the basin than at the periphery, consistent with the presence of upwelling. The small zooplankton distribution, in contrast, was heaviest near the periphery of the basin, not in the center. Large zooplankton appeared to be located mostly at the shelf break, with some areas of high concentration in the center. Large zooplankton migrated vertically at night, whereas the small zooplankton by and large did not.

Significance:
Integrated studies like the SOLMR program are now the accepted way of studying cetacean behavior and distribution (e.g. Wishner et al., 1988; Croll et al., 1998; Fiedler et al., 1998). The behavior of whales when presented with anthropogenic sounds can be

interpreted only in the context of the animals' natural behavior. This in turn can be interpreted only in the context of the animals' environment, including the distribution of prey, the overall food web, and the physical environment. The work reported here provides that context.

Work plan:
The second field season is scheduled for 21 August – 5 September, 2000. We will be working again on the *Ammiraglio Magnaghi* in the Ligurian Sea, but the study area will be larger. The physics and small plankton study will use the same methods as last year. The large zooplankton study by Dave Demer is now separately funded, and will be expanded, including a second echosounder, underwater video for *in situ* taxonomic identification, and possibly a large trawl.

An abstract is in preparation for presentation at the December meeting of the Acoustical Society of America in a special session on bioacoustics. The research will also be presented as an invited paper at the Marine Bioacoustics Symposium hosted by the Italian Consorzio Nazionale Interuniv. Per le Scienze del Mare in November.

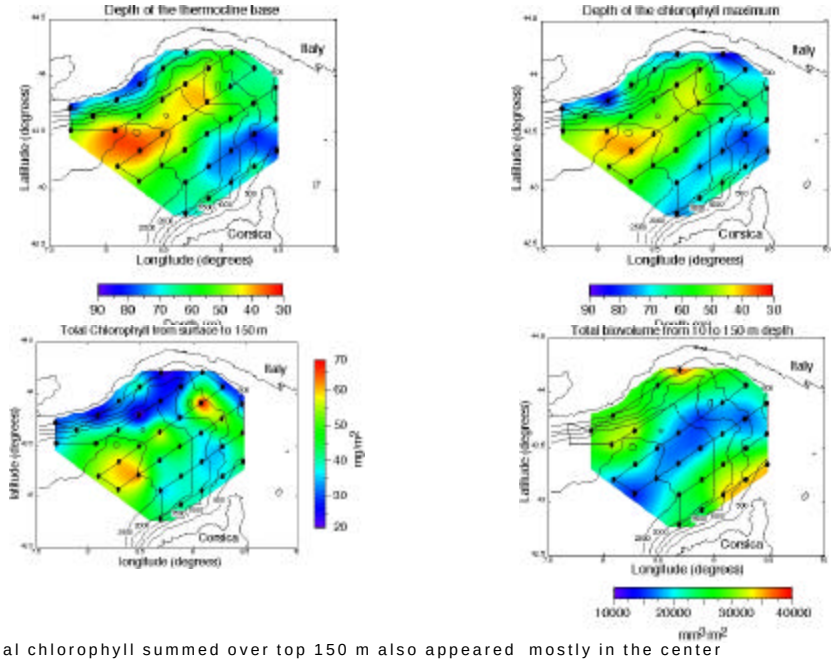
Publications, Abstracts, Technical Reports, Patents & Awards:
Citations:
None yet.

References:
Croll, D. A., Tershy, B. R., Hewitt, R. P., Demer, D. A., Fiedler, P. C., Smith, S. E., Armstrong, W., Popp, J. M., Kiekhefer, T., Lopez, V. R., et al. 1998. An integrated approach to the foraging ecology of marine birds and mammals. Deep-Sea Research II, 45: 1353-1371.

Fiedler, P. C., Barlow, J. and Gerrodette, T. 1998. Dolphin prey abundance determined from acoustic backscatter data in eastern Pacific surveys. Fishery Bulletin, 96: 237-247.

Wishner, K., Durbin, E., Durbin, A., Macaulay, M., Winn, H. and Kenney, R. 1988. Copepod patches and right whales in the great south channel off New England. Bull. Mar. Sci., 43(3): 825-844.

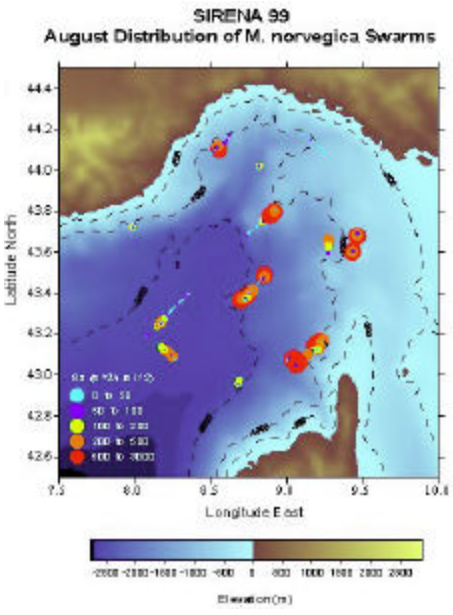
1) Doming of the thermocline in the center of the basin suggested counterclockwise circulation
2) Chlorophyll peak sat at the base of the thermocline in the Sirena 99 survey



3) Total chlorophyll summed over top 150 m also appeared mostly in the center
4) Total Small zooplankton summed over top 150 m appeared 'anticorrelated' with chlorophyll, being highest on the shelf slopes. Note: There was little evidence of vertical migration by small zooplankton.

Results from 120 kHz Echosounder

- Nighttime distribution of *Meganyctiphanes norvegica* (krill) from 7-155 m depth as mapped with a towed 120 kHz Split-beam echosounder system and summarized using echo integration methods.
- Krill swarms were only observed in the upper 150 m of the water column during hours of darkness (ca. 2000-0600 local).
- *M. norvegica* were primarily located near the 1000 m contour line, or in very deep water (center of the basin).



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR00849**
Project Title:	**Jitter Echo Delay Resolution**
Investigator(s):	**Moore, Patrick & David Helweg**
Department or Division:	**Biosciences D35**
Performing Organization:	**Space and Naval Warfare Systems Center San Diego**
Geographic Location of Study:	**San Diego, CA**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**160,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The goal of this research is to advance U.S. Navy littoral Mine Counter Measures (MCM) capabilities through study and reverse engineering of the biosonar of bottlenose dolphins (Tursiops truncatus). Dolphins are currently used very successfully in U.S. Navy Marine Mammal Systems (MMS) minehunting detachments. The specific objective of this project is to measure the limits of echo delay resolution in the dolphin using a psychophysical procedure previously applied to bats.

ANNUAL PROGRESS REPORT

Name: Moore, Helweg

Grant Number: N00014-00-WX-20336

Title: Jitter Echo Delay Resolution

Award Period: 1 Oct 1999 – 30 Sept 00

Objective:
The goal of this research is to advance U.S. Navy littoral Mine Counter Measures (MCM) capabilities through study and reverse engineering of the biosonar of bottle nose dolphins (Tursiops truncatus). Dolphins are currently used very successfully in U.S. Navy Marine Mammal Systems (MMS) minehunting detachments. The specific objective of this project is to measure the limits of echo delay resolution in the dolphin using a psychophysical procedure previously applied to bats.

Approach:
A crucial aspect of biosonar involves the structure and timing relationships between the complex highlights contained in each target backscatter echo. Although many features are present in the echo to some degree, we have demonstrated experimentally that for practical purposes only the symmetric and anti-symmetric Lamb waves of the flexural type appear to be major contributors to the time function (amplitude vs. time plot) of the backscatter echo which fall within the sensitive region of dolphin hearing. This means that the time waveform of the backscattered echo containing the various time separated highlights (due to the transfer function of the target and the ensonfying wideband pulse) needs to be experimentally examined to determine the dolphin's sensitivity to both the time separation of within-echo highlights and the relative amplitude of the highlights. Experimental procedures to estimate this sensitivity have been developed and tested using bats. The paradigm has been termed “jittered-echo delay acuity and amplitude-latency trading”. We intend to adopt these procedures, modified for the use with dolphins, to estimate this animal’s sensitivity and to compare that sensitivity to the bat.

Accomplishments:
The initial apparatus for the discrimination study has been completed. The animal has been trained to station underwater and echo-discriminate between cylinder targets simultaneously presented ahead and to the right or left of the animal. The animal echo-inspects only one target at a time as the two targets are separated by angles of 35° from the 0° midline to assure that only one can be in the emitted beam at a time. The animal has also been trained to perform a two-alternative forced choice (2AFC) response procedure. The animal presses a paddle corresponding to the position (right or left) of the "standard" target. Currently the experiment uses identical cylindrical targets (two-highlights) which differ along a time separation dimension due to the material contained inside.

The electronic apparatus for the delivery of the time-jittered echoes was ordered and has been received. Based on discussion with Dr. James Simmons it was decided that a replication of the analog system used for the original bat study would be best to use for the initial inspection of the dolphin capability so the results would be directly comparable. This required the purchase of custom built analog delay lines to provide the time delays for the analog signals. The custom-built analog delay lines were ordered and delivered but did not meet the contract specifications. This required the vendor to repair the devices and they currently have been integrated into the analog system. Based on lengthy and detailed calibration we have discovered that these delays have about a 1% error at the maximum delay of 60.0 microseconds and will be sufficient for jitter delays to about 5.0 microseconds. If the animal has sensitivity below this level then a digital system will be required This system has been purchased and is in hand.

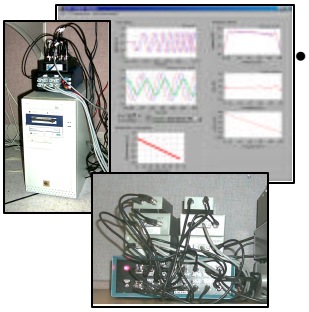
Once the animal has demonstrated acquisition of the electronic echoes we will begin the series of jittered-echo delay acuity experiments as outlined by Simmons.

Significance:
The purpose of these experiments is to investigate the capability of dolphins to form high-resolution images of targets by determine if dolphins, like bats, seem to use a deconvolution processes to perceive closely spaced highlights in echo returns. Since dolphins posses exceptional mine-hunting capabilities if this processes is discovered in dolphins then processes that produces these images will have to be implemented in man-made systems to achieve the dolphin-like mine hunting.

Work Plan:
Install the just completed analog electronic jitter system and transfer the animal from the real targets to the jitter targets. Determine the jitter threshold for the animal using the analog system. If the animal can detect jitter to the limits of the analog system replace it with the digital system and determine the JND for target jitter.

Publications, Abstracts, Technical Reports, Patents & Awards:
none

JITTER ECHO DELAY RESOLUTION



- Animal performing 2AFC discrimination of cylinder targets
  - Identical thin-walled aluminum shell
  - Material composition different
- Analog delay system
  - 4 digitally selectable delay lines
  - 0 - 60 μsecs total delay
  - 0.5 μsec accuracy

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **Office of Naval Research**

Project Identification Number: **00PR01757**

Project Title: **Marine Mammal Monitoring of Navy Undersea Acoustic Ranges (M3R)**

Investigator(s): **Moretti, David**

Department or Division: **N/A**

Performing Organization: **Naval Undersea Warfare Center, Newport**

Geographic Location of Study: **Andros Island, Bahamas**

Marine Mammal Species Involved: **various**

FY 00 Funding Level: **300,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective is to demonstrate a marine mammal monitoring system for US Navy test ranges. The AUTEC will be modified to allow the detection, identification, and tracking of marine mammals. The behavioral patterns of marine mammals in the absence of stimuli will be recorded and compared to their patterns in the presence of Navy ships and Navy activities to determine Navy impact. The capability of tracking marine mammals in Navy test ranges will also reduce the probability of detrimental impact on marine mammals by Navy activities.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02592**
Project Title:	**Cetacean Echolocation: Biosonar Experiments for Improved Navy Sonar Signal Processing**
Investigator(s):	**Nachtigall, Paul**
Department or Division:	**Hawaii Institute of Marine Biology**
Performing Organization:	**University of Hawaii**
Geographic Location of Study:	**Kanehoe, HI**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**292,883**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To enhance the capabilities of the Navy's active sonar systems through a deeper understanding of the remarkable biosonar capabilities of the bottlenose dolphin.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02603**
Project Title:	**Low Frequency Odontocete Hearing**
Investigator(s):	**Nachtigall, Paul E. & Whitlow L. Au**
Department or Division:	**Hawaii Institute of Marine Biology**
Performing Organization:	**University of Hawaii, HI**
Geographic Location of Study:	**University of Hawaii, Coconut Island Marine Lab, Kanehoe, HI**
Marine Mammal Species Involved:	**Bottlenose dolphin, False killer whale**
FY 00 Funding Level:	**153,762**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

To develop an understanding of cetacean hearing and measure the effects of loud low frequency sound on dolphin and whale hearing. To examine temporary threshold shifts with varying lengths and amplitudes of noise exposure and to provide a scientific basis for determination of risk from anthropogenic noise.

ANNUAL PROGRESS REPORT

Name: Nachtigall, Au

Grant Number: N00014-98-1-0687 Mod P0001

Title: Low Frequency Odontocete Hearing

Award Period: 15-APR-1998 - 28-FEB-2001

Objective:
To develop an understanding of cetacean hearing and measure the effects of loud low frequency sound on dolphin and whale hearing. To examine temporary threshold shifts with varying lengths and amplitudes of noise exposure and to provide a scientific basis for determination of risk from anthropogenic noise.

Accomplishments:
Temporary threshold shift studies of the bottlenosed dolphin (*Tursiops truncatus*) and false killer whale (*Pseudorca crassidens*)j continued. Bottlenosed dolphin data demonstrated a consistent threshold shift with a mean of 11.22 db re 1 μPa using a 7.5 kHz test tone when an octave band of noise between 5 and 11 kHz at 179dB re 1 μPa was presented for 55 minutes. All hearing recoved within 45 minutes. False killer whale training and exposure continues with no shifts yet observed.

Significance:
Loud low frequency sounds can effect odontocete hearing. Both exposure level and time exposed must be considered during environmental assessment of new Navy systems and the use of current systems.

Work Plan:
Continue to examine the effects of octave band noise on hearing thresholds of both bottlenosed dolphins and false killer whales. Vary amplitude and duration of exposure noise to plot time and intensity tradeoff s for TTS. Examine TTS with higher frequency test tones. Plan and begin an effort to use evoked auditory potential procedures to plot recovery time from threshold shifts. Organize experiments and begin to examine auditory localization of low frequency sounds.

Publications, Abstracts, Technical Reports, Patents & Awards:
Journal Publications:

Nachtigall, P.E. Au, W.W.L., Pawloski, J.L. & Andrews, K. Measurements of the low frequency components of active and passive sounds produced by dolphins. Submitted to *Aquatic Mammals.*

Au, W.W.L., Mobley, J., Burgess, W.C., Lammers, M. and Nachtigall, P.E. Seasonal and diurnal trends of chorusing humpback whales wintering in waters off West Maui. (In Press) *Marine Mammal Science.*

Au, W. W. L., Frankel, A., Helweg, D. and Cato, D. H. Against the humpback whale sonar hypothesis, submitted for publication to *IEEE Journal of Oceanic Engineering*.

Benoit-Bird, K. J., Au, W. W. L., Brainard, R. E., Lammers, M. O. , Diel horizontal migration of the Hawaiian mesopelagic boundary community observed acoustically," submitted for publication, *Marine Ecology Progress Series*.

Aubauer, R., Au, W.W.L., Nachtigall, P.E., Pawloski, D.A. and DeLong, C.M. (2000) Classification of electronically generated phantom targets by an Atlantic bottlenose Dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America,* 107, 2750-2754.

Au, W. W. L. and Green, M. (2000) "Acoustic interaction of humpback whales and whale watching boats," *Marine Environmental Research*. 49**,** 469-481

Kastelein, R. A., and Au, W. W. L., (2000) Detection distance of bottom-set gillnets by harbor porpoises (*Phocoena phocoena*) and bottlenose dolphins (*Tursiops truncatus*)," *Marine Environmental Research*. 49, 359-375.

Atkinson, S., Combelles, C., Vincent, D., Nachtigall, P.E., Pawloski, J. and Breese, M.(1999) Monitoring of progesterone in captive female false killer whales, *Pseudorca crassidens. General and Comparative endocrinology*, 115, 323-332.

Moehl, B., Au, W.W.L., Pawloski, J.L. and Nachtigall, P.E**.** (1999) Dolphin hearing: Relative sensitivity as a function of point of application of a contact sound source in the jaw and head region. *Journal of the Acoustical Society of America.* 105, 3421-3424

Roitblat, H. L., Nachtigall, P. E., Au, W. W. L., Shizumura, R., & Moons, G. (1999). Classifying buried targets by mimicking dolphin echolocation. In Y.-C. Teng, E.-C. Shang, Y.-H. Pao, M. H. Schultz, and A. D. Pierce (Eds.): *Theoretical and computational acoustics* '97. (pp. 553-559). Singapore: World Scientific Publishing.

Au, W. W. L., Kastelein, R. A., Rippe, T., and Schooneman, N. M. (1999). Transmission Beam Pattern and Echolocation Signals of a Harbor Porpoise (*Phocoena phocoena*), *Journal of the Acoustical Society of America*, 196, 3699-3705.

Kastelein, R. A., Au, W. W. L., Rippe, T., and Schooneman, N. M. (1999). Target detection by an echolocating harbor porpoise (*Phocoena phocoena*), *Journal of the Acoustical Society of America* 105, 2493-2498.

Au, W. W. L., Lammers, M. O., and Aubauer, R. (1999). "A Portable Broadband Data Acquisition System for Field Studies in Bioacoustics," *Marine Mammal Science*. 15, 526-531.

Invited Presentations:

Nachtigall, P.E. Echolocation through Sediments. *Invited Keynote Speaker*, Ocean Day 99:Hawaii's Oceans at the Dawn of the new Millenium, 2 June, 1999, State of Hawaii and PACON International, Honolulu, Hawaii.

Au, W.W.L. Echolocation in Dolphins. *Invited Plenary Address*, 13th Biennial Conference on the Biology of Marine Mammals. November 28- December 3, 1999, Wailea, Maui.

Au, W. W. L., Nachtigall, P. E., and Pawloski, J. L. Temporary threshold shift in hearing induced by an octave band of continuous noise in the bottlenose dolphin, Acoustical

Society of America Meeting. Abstract in *Journal of the Acoustical Society of America* 106, p 2251.

Books or book chapters published:

Au, W. W. L., Popper, A., and Fay, R., (2000). *Hearing by Whales and Dolphins*, Springer-Verlag, New York.

Nachtigall, P.E., Lemonds, D.W., and Roitblat, H.L. (2000) Psychoacoustic Studies of Dolphin and Whale Hearing. In: *Hearing by Whales and Dolphins,* Au, W.W.L., Popper, A.N., and Fay R.R., Springer-Verlag, New York, pp 330-361.

Au, W.W.L., (2000) Hearing in Whales and Dolphins: An Overview. In: *Hearing by Whales and Dolphins,* Au, W.W.L., Popper, A.N., and Fay R.R., Springer-Verlag, New York, pp. 1-42.

Au, W.W.L., (2000) Echolocation in Dolphins. . In: *Hearing by Whales and Dolphins,* Au, W.W.L., Popper, A.N., and Fay R.R., Springer-Verlag, New York, pp. 365-408.

Lammers, M. O., Au, W. W. L., Aubauer, R., and Nachtigall, P. E. (In press). "A comparative analysis of the pulsed emissions of free-ranging Hawaiian spinner dolphins (Stenella longirostris)." in *Echolocation in bats and dolphins*, edited by J. Thomas, C. Moss, and M. Vater (University of Chicago press, Chicago).

Philips J., Au, W., Nachtigall, P., Pawloski, J. and Roitblat, H. (in press). "Echolocation in the Risso's dolphin, Grampus griseus: a preliminary report." in *Echolocation in bats and dolphins*, edited by J. Thomas, C. Moss, and M. Vater (University of Chicago press, Chicago).

Au, W. W. L. (in press). Odontocete echolocation, in *Encyclopedia of Marine Mammals*, Edited by W. F. Perrin, B. Wursig, H. G. M. Thewissen, Academic Press, San Diego.

Au, W. W. L. A comparison of the sonar capabilities of bats and dolphins, (in press). in *Echolocation in bats and dolphins*, edited by J. Thomas, C. Moss, and M. Vater (University of Chicago press, Chicago).

Roitblat, H.L. Object Recognition by Dolphins(in press). In *Echolocation in bats and dolphins*, edited by J. Thomas, C. Moss, and M. Vater (University of Chicago press, Chicago).

Au, W. W. L. (in press). "Bioacoustics Animal" in *Encyclopedia of Science & Technology*, edited by M. Licker, McGraw-Hill, New York.

Schotten, M., Au, W. W. L., Lammers M. O., and Aubauer R. (in press). "Echolocation recordings and localizations of wild spinner dolphins (*Stenella longirostris*) and pantropical spotted dolphins (*Stenella attenuata*) using a four hydrophone array," in *Echolocation in bats and dolphins*, edited by J. Thomas, C. Moss, and M. Vater (University of Chicago press, Chicago).

Ridgway, S. H., and Au, W. W. L. (1999). "Hearing and echolocation: Dolphin," in *Elsevier's Encyclopedia of Neuroscience*, edited by G. Adelman and B. Smith, Elsevier Science, New York, pp. 858-862.

Andersen, L. N., Au, W. W. L., Larsen, J., and Hansen, L. K. (1999). "Sonar Discrimination of cylinders from differetn angles using neural networks," ICASSP'99, edited by J. Rodriguez, pp. 1121-1124.

Ridgway, S. H., and Au, W. W. L. (1999). "Hearing and echolocation: Dolphin," in Elsevier's *Encyclopedia of Neuroscience*, edited by G. Adelman and B. Smith, Elsevier Science, New York, pp. 858-862.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**99PR01960**
Project Title:	**Blubber: an elastic energy storage system in parallel with the swimming muscles of dolphins**
Investigator(s):	**Pabst, D. Ann**
Department or Division:	**Biology**
Performing Organization:	**University of North Carolina, Wilmington**
Geographic Location of Study:	**University of North Carolina & University of California, Santa Cruz**
Marine Mammal Species Involved:	**Bottlenose Dolphin, others**
FY 00 Funding Level:	**27,565**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To test the hypothesis that caudal tailstock blubber functions as a spring, in parallel with the swimming muscles of dolphins, to decrease their energetic costs of locomotion. To test, we (1) measure *in vivo* blubber strains, coupled with force output and kinematics of exercising dolphins, (2) test blubber's mechanical properties, and (3) analyze blubber's structural fibers and lipid content.

ANNUAL PROGRESS REPORT

Name: Pabst

Grant Number: N000149710517

Title: Blubber: an elastic energy storage system in parallel with the swimming muscles of dolphins

Award Period: 01 April 1997 – 30 September 2000

Objective:
To test the hypothesis that caudal tailstock blubber functions as a spring, in parallel with the swimming muscles of dolphins, to decrease their energetic costs of locomotion.

Approach:
To test this hypothesis we (1) measure *in vivo* blubber strains, coupled with force output and kinematics of exercising dolphins, (2) test blubber's mechanical properties, and (3) analyze blubber's structural fibers and lipid content.

Accomplishments:
(1) In collaboration with Dr. Terrie Williams, we completed simultaneous records of blubber strains and kinematics for two exercising bottlenose dolphins (*Tursiops truncatus*). These data indicate that dorsal keel strains vary along the length of the tailstock. Near the dorsal fin, the keel undergoes large sinusoidal strains; maximum tensile strains occurs in-phase with maximum tailstock deflection. This blubber appears to be acting as a spring to store and release useful strain energy. (2) Microscopy studies of the structural fiber architecture blubber of harbor porpoise (*Phocoena phocoena*) and common dolphin (*Delphinus delphis*) were completed. The spring function of cetacean blubber is dependent upon its composite fiber architecture. Blubber's tensile fibers form a lipostatically supported skeleton by surrounding compression-resistant adipocytes. Both histochemical and ultrastructural analyses of the integument of common dolphin have revealed that adipocytes are wrapped by thin reticular fibers. These adipocytes are, in turn, surrounded by collagen fiber bundles. The collagen fibers are also connected by elastin fibers that wrap the fibers and often cross over from one collagen fiber or bundle to another. At high magnification these elastin fibers can be seen to be anchored in the periphery of the collagen, terminating in fine oxytalan fibers. A differential distribution of collagen types in the large collagen bundles was suggested by one histochemical treatment, but analysis of the distribution of fiber diameters within the large bundles did not support such a distribution. In summary, the results suggest that the components of the integument are highly integrated, from the macroscopic to the ultrastructural scale. (3) We have begun working with Dr.'s Peter Tyack and Doug Nowacek, Woods Hole Oceanographic Institute, to investigate swimming records of right whales (*Eubalaena glacialis*), gathered by non-invasively applied DTAG, to test the predictions of the

scaling model of spring function generated by our collaboration with Dr. John Long, Vassar College.

Significance:
The results of our morphological, mechanical and kinematic studies, coupled with those from scaling models, suggest that cetaceans of all sizes employ a blubber spring to decrease their metabolic costs of swimming. Blubber's regionally specific mechanical behavior, as predicted by composite theory, is controlled by specific distributions of biomaterials along its length. Near the dorsal fin, blubber undergoes large sinusoidal strains during swimming; maximum strain occurs in-phase with maximum deflection of the tailstock, suggesting blubber is acting as a spring, in-parallel with swimming muscles. At a position cranial to the insertion of the flukes, the keel undergoes little strain, and is three orders of magnitude stiffer than blubber near the fin. This blubber appears to function as an anchor for the spring blubber. At the fluke base, the blubber undergoes two extensions/locomotor sequence, once near the maximum ventral, and again at the maximum dorsal, deflection of the tailstock. This blubber appears to absorb energy imparted onto the tailstock by the flukes as they change their position throughout the tailbeat. Engineers may gain insights from blubber's fiber architectures when designing human-made, oscillating propulsors, as a recent mathematical model by Harper *et al*. (1998; J. Ocean. Engin. 23:285-296) demonstrated large energy savings by incorporating springs into oscillating foil-propulsors.

Work Plan: W
We will complete analyses of morphological and mechanical data and publish research findings.

Publications, Abstracts, Technical Reports, Patents & Awards:
Publications:
Pabst, D.A. 2000. To bend a dolphin: convergence of force transmission designs in cetaceans and scombrid fishes. *American Zoologist*. 40:146-155.

Pabst, D.A., Rommel, S.A. and W.A. McLellan. 1999. Functional morphology of marine mammals. In: *Biology of Marine Mammals* (eds. J.E. Reynolds and S.A. Rommel) Smithsonian Press, pp. 15-72.

Pabst, D.A., Hamilton, J.L., McLellan, W.A., Williams, T.M., and J.M. Gosline. 1999. Streamlining dolphins: designing soft-tissue keels. Proceedings of the Eleventh International Symposium on Unmanned, Untethered Submersible Technology. Autonomous Undersea Systems Institute.

Dearolf, J.L., McLellan, W.A., Dillaman, R.M., Frierson, Jr., D., and D.A. Pabst. 2000. Precocial development of axial locomotor muscle in bottlenose dolphins (*Tursiops truncatus*). *Journal of Morphology.* 244(3):203-215.

Presentations:
Pabst, D. A. 1999. Opening Plenary Address: Locomotor functions of dolphin blubber. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Pabst, D. A., McLellan, W.A., and Williams, T. M. 1999. Locomotor functions of dolphin blubber. American Zoologist. 39(5):114A.

Dearolf, J.L., McLellan, W.A., Pabst, D.A., and Hermanson, J.W. 1999. Ventilation in bottlenose dolphins (*Tursiops truncatus*): The role of the diaphragm. American Zoologist. 39(5):98A.

Hamilton, J. L., McLellan, W. A., and Pabst, D. A. 1999. Structural fiber reinforcement of tailstock blubber of the harbor porpoise (*Phocoena phocoena*). The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

McLellan, W. A., Friedlaender, A. S., Mead, J. G., Potter, C. W., Thayer, V. G., and Pabst, D. A. 199. An analysis of *Tursiops* strandings along the Eeastern U.S. Coast for the years 1972-1997. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

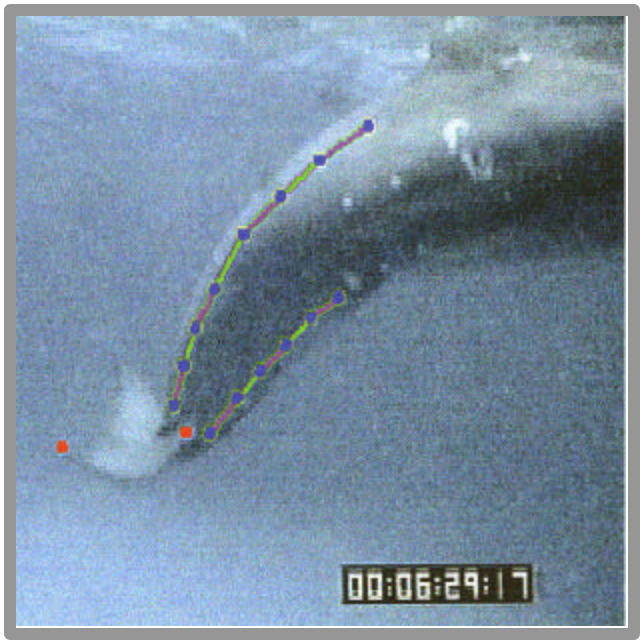
Nill, E. K., Pabst, D. A., Rommel, S. A., and McLellan, W. A. 1999. Does the thick skin of the Florida Manatee (*Trichechus manatus latirostris*) provide ballast? The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Nill, E. K., Pabst, D. A., Rommel, S. A., and McLellan, W. A. 1999. Does the thick skin of the Florida Manatee (*Trichechus manatus latirostris*) provide ballast? American Zoologist. 39(5):114A.

Noren, D. P., Williams, T. W., Haun, J. E., and Pabst, D. A. 1999.The effect of exercise on heat flow from the extremities and thermoregulation of the intra-abdominal testes of the bottlenose dolphin (*Tursiops truncatus*). The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Stegall, V. K., McLellan, W. A., Dillaman, R. M., Read, A. J., and Pabst, D. A. 1999. Epaxial muscle morphology of robust *versus* emaciated harbor porpoises, *Phocoena phocoena*. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Stegall, V. K., McLellan, W. A., Dillaman, R. M., Read, A. J., and Pabst, D. A. 1999. Epaxial muscle morphology of robust *versus* emaciated harbor porpoises, *Phocoena phocoena*. American Zoologist. 39(5):84A.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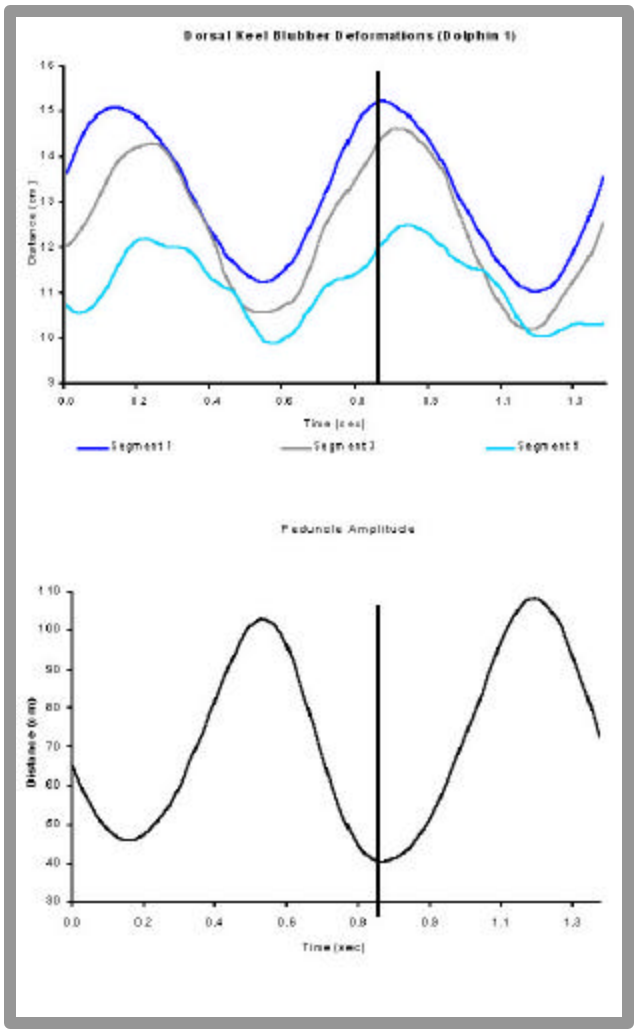
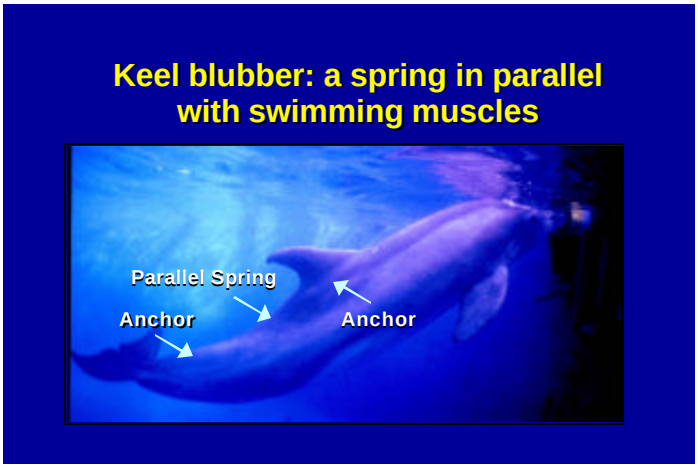

Dorsal Keel Blubber Deformations (Dolphin 1)
Distance (cm)
Time (sec)
Segment 1
Segment 3
Segment 5
Peduncle Amplitude
Distance (cm)
Time (sec)


Keel blubber: a spring in parallel with swimming muscles
Parallel Spring
Anchor
Anchor

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **Office of Naval Research**

Project Identification Number: **00PR02872**

Project Title: **Bioacoustic characterization of the Mediterranean Sea**

Investigator(s): **Pavan, Gianni**

Department or Division: **Bioacoustics**

Performing Organization: **University of Pavia**

Geographic Location of Study: **Mediterranean Sea**

Marine Mammal Species Involved: **various**

FY 00 Funding Level: **150,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The long term goal is to create a comprehensive database on marine mammals and ecosystem dynamics in the Mediterranean Sea to support Acoustic Risk Mitigation Policies. In the short term, the technical objectives are to develop and test acoustic detection, monitoring and classification instruments and procedures, including the development of portable systems for the real-time visualization of underwater biological sounds, and to develop a centralized database for living marine resources in the Mediterranean Sea. The research is within the scopes of the Saclantcent's Joint Research Project entitled Sound, Oceanography and Living MArine Resources (SOLMAR), which is an interdisciplinary program that addresses the issue of underwater noise and its effects on the marine environment.

ANNUAL PROGRESS REPORT

Name: Pavan

Grant Number: N00014-99-1-0709

Title: Bioacoustic characterization of the Mediterranean Sea

Award Period: May 1, 1999 – April 30, 2001

Objective:
The long term goal is to create a comprehensive database on marine mammals and ecosystem dynamics in the Mediterranean Sea to support Acoustic Risk Mitigation Policies.

In the short term, the technical objectives are to develop and test acoustic detection, monitoring and classification instruments and procedures, including the development of portable systems for the real-time visualization of underwater biological sounds, and to develop a centralized database for living marine resources in the Mediterranean Sea.
The research is within the scopes of the Saclantcent's Joint Research Project entitled Sound, Oceanography and Living MArine Resources (SOLMAR), which is an interdisciplinary program that addresses the issue of underwater noise and its effects on the marine environment.

Approach:
Through ONR funding in 1999-2000, the University of Pavia participates in the SOLMAR project by providing its expertise in the organization of acoustic and visual surveys to detect and locate marine mammals, to classify their sounds and to study their behaviour taking into account biological and oceanographical parameters.
The interdisciplinary approach includes setting up databases and associated GIS to provide historical and actual information on marine mammals occurring in the Mediterranean Sea (strandings, sightings, acoustic detections, literature).
At present, the database(s) hold stranding information for the Italian coasts (1986-1998), data provided by CIBRA (data collected in 1991-1998 – including sightings, sound recordings, slides, video clips) and data found in literature.

An important part of the project is the organization of visual and acoustic surveys on different platforms, including platforms of opportunity.
The acoustic research is carried out by using an analysis software (wSpecGram) developed by the PI which provides 2 channel sound recording with real-time analysis and display capabilities on notebooks (a Pentium II cpu is required) as well as on desktop PCs. The software runs on Win95/98/NT/2000. Additional features developed within this project allow to analyze and to play data files generated by Saclantcen instruments (beamformer). An advanced version (DaqSpecGram) allows ultrasound recording and analysis on notebooks equipped with a high speed acquisition system.

Accomplishments:
As the Grant started on May 1, 1999, most of the activities are still undergoing. The initial effort of CIBRA was mostly concerned with:
a) support to the Saclantcent in setting up the SOLMAR Joint Research Project which included setting up databases and participating in the research cruises Sirena 99 with related activities.
b) analysis of data collected by CIBRA in previous years (sound recordings, acoustic measures, visual observations, stranding data, scientific papers) for their inclusion into SOLMAR databases and for supporting SOLMAR goals.
c) setting up instrumentation

May/August 1999:
Support to Saclantcent in setting up the required instrumentation and data collection protocols for the summer cruises Sirena 99. Development and testing of a notebook-based portable workstation for sound recording and analysis in the field. Adapting CIBRA software for the specific needs of the research. Design and filling of strandings' database. Four CIBRA researchers participated in these activities; two of them participated within a 3 months internship (SRA) at Saclantcent.

August/September 1999:
Participation to two research cruises in the Ligurian Sea organized by the Saclantcent to test and apply Dual Use Technologies for the detection, location and tracking of marine mammals. Three CIBRA researchers participated on the R/V Alliance for conducting visual and acoustic surveys. Two CIBRA researchers participated – within their three months internship at Saclantcent - on the Italian Navy's R/V Magnaghi to perform an acoustic survey with sonobuoys and to help in a plankton survey at the same time.
Organization of a short research cruise with an auxiliary motorsailing vessel for studying marine mammals occurring in the Ligurian Sea and for testing new portable instruments.
The cruises allowed the recording of sounds from Physeter macrocephalus (Sperm whale), Globicephala melas (Long finned pilot whale), unidentified dolphins, and, for the first time in the Mediterranean Sea, of Balaenoptera physalus (Fin whale). In these cruises a new class of sounds – named "nacchere" still to be linked to a species - has been extensively recorded.

Autumn/Winter 1999:
Analysis of collected data, improvement of analysis techniques and instruments, collecting data for the databases.

Spring 2000:
Analysis of data and development of procedures for the cruise Sirena 2000. Support in the development of the SOLMAR website. Acquisition/design/testing of new instrumentation for field use.

Significance:
This project supports the goals of the US Navy's research program on the effects of underwater noise on the marine environment. The research is aimed at developing the instruments, the procedures and the skills required to detect the marine mammals present in a certain area, to classify their sounds and to monitor any eventual responses to man-made sounds or to other actions. A further goal is to create the foundation for a comprehensive database on marine mammals occurring in the Mediterranean Sea.
The objective of the research cruises Sirena 99 and Sirena 2000 with the R/V Alliance (NATO Saclantcen) is to demonstrate Dual Use Technology for the detection, localization, classification and tracking of marine mammals using several deployed hydrophone arrays. This will allow the comparison of different monitoring techniques to support the Saclantcen Acoustic Risk Mitigation Policy.

TECHNOLOGY TRANSFER:
The real-time sound analysis software 'wSpecGram' with the new functions developed within the ONR grant is used by NATO Saclantcent in the SOLMAR Project for the passive acoustic monitoring requirements of the Risk Mitigation Policies.
The software has been requested for evaluation by the German Navy and by several researchers.

Acoustic signatures of marine mammals collected within the ONR grant, as well as recordings made by CIBRA in previous years, have been requested by the Royal Navy (UK).

Sightings data and acoustic data collected by CIBRA in years 1994-1997 have been included into Saclantcent databases and GIS. Continuous recordings of diving sperm whales have been used at Saclantcent to develop and test new analysis software and models.

The classification scheme for biological sounds occurring in the Mediterranean Sea developed by CIBRA is used in the Saclantcent SOLMAR project and has been adopted as a basis for developing automatic acoustic classification software.

Work Plan:
Summer 2000:
Scientific support and participation to the cruise Sirena 2000 on the R/V Alliance and to survey flights with Italian Navy's ASW patrolling aircrafts. Analysis of the collected acoustic data and comparison of results obtained with different detection instruments and methodologies.
Scientific support and participation to whale-watching cruises in the Ligurian Sea and in Sardinian Sea.

Summer/Autumn/Winter 2000:
Organization of short research cruises and acoustic surveys in the Ligurian Sea focusing on the study of Cuvier's beaked whales and on developing approach techniques to eventually support tagging efforts. A further goal of these cruises will be the study of the

"nacchere", a sound category often recorded but never definitively associated to a species, to possibly identify the emitting species.
Development of a lightweight towed array for marine mammal surveys in cooperation with other Institutions to better support field research on small platforms.
Improvement of the sound analysis software and extension to multichannel display.

Publications, Abstracts, Technical Reports, Patents & Awards:

Presentations to conferences authored or coauthored by CIBRA researchers:

Convegno Unione Zoologica Italiana (UZI), Pavia, september 1999

Pavan G. - La bioacustica subacquea per lo studio dei mammiferi marini. Ricerche, risultati e prospettive in Mediterraneo. Relazione.

4° Convegno Nazionale sui Cetacei e sulle Tartarughe marine, Milano, Italy, 11 e 12 november 1999:

Fossati C., D'Amico A., Manghi M., Pavan G., Podestà M., Portunato N., Priano M., Teloni V. – Osservazioni cetologiche e oceanografiche: un sistema geografico informativo (GIS) per la loro organizzazione e integrazione nel Mar Mediterraneo. Talk.

D'Amico A., Bondaryk J. E., Fossati C., Manghi M., Pavan G., Portunato N., Priano M. – Rilevamento acustico e localizzazione dei mammiferi marini in Mar Ligure. Talk.

Pavan G. – Workstation portatile per la registrazione e l'analisi acustica. Poster.

Teloni V., Montesi G., Fossati C., Manghi M., Pavan G., Priano M. – Monitoraggio acustico e visivo della cetofauna del Mar Ligure e Tirreno settentrionale. Poster.

14 th ECS Conference, Cork (Ireland), 2-5 april 2000:

Teloni V., Zimmer W.M.X., Fossati C., Manghi M., Pavan G., Priano M. - Variability of temporal and spectral click characteristics of sperm whales (*Physeter macrocephalus*). Talk.

D'Amico A., Podesta M., Portunato N., Teloni V., Williams A., Fossati C., Manghi M. - Cetacean visual sightings in Sirena 99: a sound oceanography and living marine resources project research cruise. Poster.

Results and images produced by CIBRA have been included in other presentations authored by Saclantcent

Papers authored or coauthored by CIBRA researchers:

Fossati C., D'Amico A., Portunato N., Pavan G., Podesta M., 1999. Application of graphical digital tools to stranding information: an open information system for marine mammal studies in the Mediterranean Sea. European Research on Cetaceans, 13: 465-466.

Teloni V., Zimmer W.M.X., Fossati C., Manghi M., Pavan G., Priano M. - Variability of temporal and spectral click characteristics of sperm whales (*Physeter macrocephalus*). European Research on Cetaceans: submitted.

Internal Technical Reports:

SOLMR Project: SIRENA'99 Cruise, R/V Alliance, 2-14 August 1999. Preliminary findings. Published by Saclantcent, CDROM n.27.

Reports or papers in preparation:

wSpecGram – Real-time Sound Analysis Software for desktop and notebook PCs.

DSPW & Portable DSPW – A Digital Signal Processing Workstation for monitoring marine mammal sounds

Report: SOLMR Project: SIRENA'99 Cruise, R/V Alliance, 2-14 August 1999. Acoustic results.

Report: SOLMR Project: SIRENA'99 Cruise, R/V Magnaghi, 2-14 August 1999. Acoustic results.

Report: Recording fin whale sounds in the Mediterranean Sea

Report: Aleph cruise (September 1999).

Papers published in 1999 and 2000 based on previous activities not funded by ONR:

Benoldi C., Gill A., Evans P.G.H., Manghi M., Pavan G., Priano M., 1999. Comparison between Risso's dolphin vocal repertoire in Scottish waters and in the Mediterranean Sea. European Research on Cetaceans, 12: 235-239.

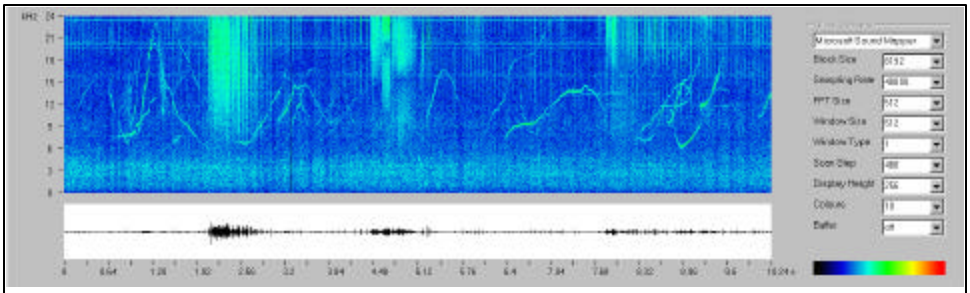
Bonsignori B., Gnone G., Pavan G., Benoldi C., Manca S., Manghi M., Priano M., 1999. Acoustic ethogram of the Bottlenose dolphin in captivity. European Research on Cetaceans, 12: 240-245.

Manghi M., Fossati C., Priano M., Pavan G., Borsani J.F., Bergamasco C., 1999. Acoustic and visual methods in the Odontocetes survey: a comparison in the Central Mediterranenan Sea. European Research on Cetaceans, 12: 251-253.

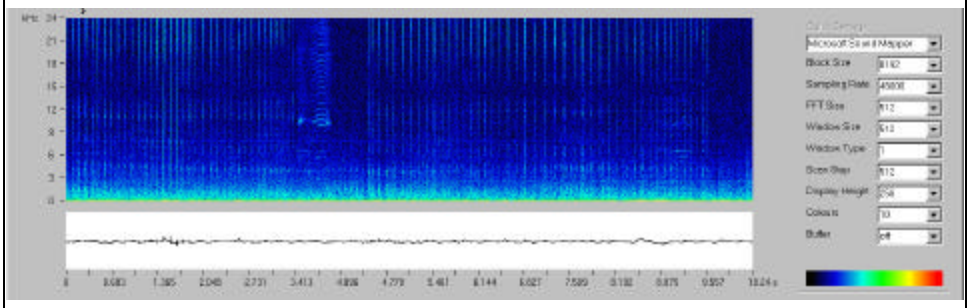
Pavan G., Fossati C., Manghi M., Priano M., 1999. Acoustic measure of body growth in a photo-identified sperm whale. European Research on Cetaceans, 12: 254-258.

MANGHI M., MONTESI G., FOSSATI C., PAVAN G., PRIANO M., TELONI V., 1999. Cuvier's beaked whales in the Ionian Sea: first recordings of their sounds. European Research on Cetaceans, 13: 39-42.

G. PAVAN, T. HAYWARD, J. F. BORSANI, M. PRIANO, M. MANGHI, C. FOSSATI, J. GORDON, 2000. Time Pattern of Sperm Whale Codas Recorded in the Mediterranean Sea 1985–1996. J.Acoust.Soc.Am, 107 (6): 3487-3495.



Wide band recording of whistles, clicks and bursts emitted by striped dolphins. (Aleph 99).
A special processing enhances the ability to detect dolphins.
Whistles and bursts are detectable above 8 kHz.



Wide band recording of “nacchere”. Series of clicks heard mostly in dark hours, few seconds in duration, interclick interval 60 - 120 msec, often interspersed with whistles and/or burst of fast clicks. (Aleph 99).

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01644**
Project Title:	**Assessment Of Mechanical Damage To Odontocete Respiratory Tract Tissues After Controlled Exposure To Blasting**
Investigator(s):	**Reidenberg, Joy S. & Jeffrey T. Laitman**
Department or Division:	**Cell biology and Anatomy**
Performing Organization:	**Mount Sinai School of Medicine**
Geographic Location of Study:	**Mount Sinai School of Medicine**
Marine Mammal Species Involved:	**Odontocetes**
FY 00 Funding Level:	**20,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To determine whether artificially generated blast pressures damage the tissues of the odontocete respiratory tract. While the odontocete respiratory tract is adapted to withstand the relatively gradual pressure changes associated with diving, nothing is known about how it responds to the sudden pressure changes of a blast exposure.

ANNUAL PROGRESS REPORT

Name: Reidenberg, Laitman

Grant Number: N00014-99-1-0815

Title: Assessment Of Mechanical Damage To Odontocete Respiratory Tract Tissues After Controlled Exposure To Blasting

Award Period: 1999-2002, three years

Objective:
To determine whether artificially generated blast pressures damage the tissues of the odontocete respiratory tract. While the odontocete respiratory tract is adapted to withstand the relatively gradual pressure changes associated with diving, nothing is known about how it responds to the sudden pressure changes of a blast exposure.

Approach:
The respiratory tract (e.g., nasal cavities, larynx, trachea, lungs) is examined to determine whether blast pressures cause damage, or whether it is naturally protected by diving adaptations. Tissues will be harvested from freshly dead odontocetes obtained from naturally occurring strandings, from post-mortem odontocete specimens artificially exposed to blast pressures (supplied by Dr. Ketten), and from normal terrestrial and non-cetacean aquatic mammals. Tissues will be compared and examined grossly and histologically for damage (hemorrhage, fractures). We will also look for indications of an ability to react to compression or stretch, e.g., the presence and distribution of elastic fibers or folded tissues.

Accomplishments:
During this past year, we have collected fresh tissues from two live-stranded odontocetes (sperm whale, Physeter macrocephalus), two blast-pressure exposed odontocetes (striped dolphin, Stenella coeruleoalba, Atlantic white-sided dolphin, Lagenorhynchus acutus), five non-cetacean aquatic specimens (West Indian/Florida manatee, Trichechus manatus, northern elephant seal, Mirounga angustirostris) and several terrestrial specimens. We have made gross observations, and are currently processing the histological tissues. To enable unbiased observations, we have NOT been informed of the exposure levels of the blast pressures applied to the specimens supplied by Dr. Ketten. Preliminary gross observations indicate that the two specimens from Dr. Ketten show evidence of traumatic hemorrhage compared with beach-stranded specimens (including those in our collection dissected prior to this project). The damage is most noticeable in the lungs (alternating light and dark stripes that correlate with the locations of the ribs). The trachea and larynx show dark red coloration (hemorrhage) in areas that were in contact with gas-containing spaces, but look relatively normal (pinkish coloration) in areas contacting other flesh (e.g., region of palatopharyngeal sphincter). Some portions of the nasal region (e.g., air sacs and nasal plugs) also show evidence of hemorrhage.

Significance:
Comment on the scientific impact and the Naval impact, if known. Where appropriate, include specific information about S&T transfers to other ONR programs or transitions of your results to industry, including a start-up company, or to Naval acquisition programs.

This project will provide crucial environmental impact information on whether the odontocete respiratory tract is capable of withstanding sudden, large pressure changes such as the shock waves that result from underwater blasting. An air-filled cavity of fixed volume may be particularly susceptible to blast damage due to the greater compressibility of gas versus fluid or solid. The largest air-filled "cavity" is comprised of the contiguous spaces of the respiratory tract (of which the middle ear is only a small air-filled extension). It is not clear whether the rapid compression and expansion associated with blast exposure affects the cetacean respiratory tract. Serious injury to the respiratory tract could be immediately lethal since it affects respiration. Knowledge about the potential susceptibility of the respiratory tract is thus essential for making informed decisions that authorize or deny blasting in proximity to critical cetacean habitats.

Work Plan:
We plan to continue collecting and analyzing tissues from specimens in all three categories: 1) stranded odontocetes not exposed to blast pressures, 2) post-mortem odontocete specimens exposed to blast pressures, and 3) normal non-odontocete specimens. Specimens exposed to blast pressures will be supplied by Dr. Darlene Ketten according to the schedule developed for her ONR funded project. Once all tissues are collected and analyzed, we will be informed of the levels of blast pressure exposure for each specimen supplied by Dr. Ketten. We will write up our results for publication.

Publications, Abstracts, Technical Reports, Patents & Awards:
SELECTED CITATIONS, 1999-2000:

Reidenberg, J.S. and Laitman, J.T. (1999) Identifying the sound source in mysticetes. Eur. Res. Cetaceans 12:259-261.

Laitman, J.T. and Reidenberg, J.S. (1999) Evolution of the vocal folds in cetaceans. Eur. Res. Cetaceans 12:286-289.

Laitman, J.T. and Reidenberg, J.S. (1999) CD-ROM Comparative and developmental anatomy of laryngeal position. In: Head and Neck Surgery - Otolaryngology, Vol. 1, 2nd Edition. B.J. Bailey (ed.), J.B. Lippincott Co., Philadelphia.

Laitman, J.T. (1999) Human speech origins. In: Encyclopedia of Human Evolution and Prehistory, 2nd Edition. I. Tattersall, E. Delson, J. Van Couvering, and A. Brooks (eds.), Garland Press, New York.

Reidenberg, J.S. (1999) Teaching the youngest anatomists. Anat. Rec. (New Anatomist) 257:125-127.

Aroyan, J.L., McDonald, M.A., Webb, S.C., Hildebrand, J.A., Clark, D., Laitman, J.T. and Reidenberg, J.S., (2000) Acoustic models of sound production and propagation. In: W. Au, R. Fay, and A. Popper (eds.), Hearing in Whales and Dolphins, Springer-Verlag, NY. pp. 409-469.

Reidenberg, J.S. and Laitman, J.T. (2000) From the beach to the bench: Research on mysticete larynges and comparisons with those of odontocetes. Proceedings of the 17th Annual Northeast Region Stranding Conference, May 20 to May 23, 1999, Baltimore, Maryland. p.38, plus "Notes from the presentation."

Reidenberg, J.S. and Laitman, J.T. (2000, in press) Prenatal development in cetaceans. In: Encyclopedia of Marine Mammals, W.F. Perrin, B. Wursig, and H.G.M. Thewissen (eds.), Academic Press, San Diego.

Reidenberg, J.S., and Laitman, J.T. (2000, in press) The mystery of the odontocete larynx. Feature Article, Pacific Cetacean Group Newsletter "Upwellings"

Reidenberg, J.S., Weinrich, M.T., and Laitman, J.T. (submitted, under revision) A proposed laryngeal mechanism for bubble cloud production by humpback whales (Megaptera novaeangliae). Marine Mammal Science

Presentations at meetings published as Abstracts:

Reidenberg, J.S. and Laitman, J.T. (1999) Cranial asymmetry and hyolaryngeal position: Evidence from toothed whales. Assoc. Res. Otolaryngol. Abstr. Vol. 22:21. (meeting of the Association for Research in Otolaryngology)

Reidenberg, J.S. and Laitman, J.T. (1999) Respiratory tract asymmetry and hyolaryngeal position in odontocete cetaceans. FASEB Journal 13:A679. (meeting of the American Association of Anatomists)

Reidenberg, J.S. and Laitman, J.T. (1999) Experimental and comparative evidence shows direct cranial-hyolaryngeal relationships in the vertical and horizontal axes: Implications for reconstruction in fossil hominids. Am. J. Phys. Anthropol., Suppl. 28:230. (meeting of the American Association of Physical Anthropologists)

Reidenberg, J.S. and Laitman, J.T. (1999) Hyolaryngeal asymmetry may explain why dolphins strand-feed on their right side. Biennial Conference on the Biology of Marine Mammals, 13:155-156. (meeting of the Society for Marine Mammalogy)

Reidenberg, J.S. and Laitman, J.T. (2000) Posterior protection of the respiratory tract. FASEB Journal, p.A782. (meeting of the American Association of Anatomists)

Balboni, A.L., Bergemann, A.D., Reidenberg, J.S., and Laitman, J.T. (2000) A molecular exploration of the branchial arches: Implications for understanding development of the aerodigestive tract. FASEB Journal, p.A279. (meeting of the American Association of Anatomists)

Reidenberg, J.S. and Laitman, J.T. (2000) Mammalian vocalizing via pneumatic mechanisms: Specialization for an aquatic environment. Assoc. Res. Otolaryngol. Abstr. Vol. 23:161. (meeting of the Association for Research in Otolaryngology)

Balboni, A.L., Bergemann, A.D., Cole, F., Reidenberg, J.S., and Laitman, J.T. (2000) New insights into the development of the aerodigestive tract: Molecular relationships among branchial arches. Assoc. Res. Otolaryngol. Abstr. Vol. 23:249. (meeting of the Association for Research in Otolaryngology)

Reidenberg, J.S. and Laitman, J.T. (2000) A disadvantage of being human: Poor posterior protection of the airway. Am. J. Phys. Anthropol., Suppl. 30:260-261. (meeting of the American Association of Physical Anthropologists)

Selected Invited Lectures:

”Anatomy of Sound Production in Cetaceans,” The McGrath Lecture Series on Current Topics in Marine Science, South Hampton College of Long Island University, 2000 by Joy Reidenberg.

”Comparative and Developmental Anatomy of the Mammalian Larynx,” Karl Storz Memorial Lectureship, American Society for Pediatric Otolaryngology, 2000, by Jeffrey Laitman.

International Awards Received 1999-2000:

Basmajian/William and Wilkins Award of the American Association of Anatomists (for “Outstanding accomplishments in research in the anatomical sciences and demonstrated excellence in and commitment to the teaching of gross anatomy”), awarded to Joy Reidenberg, 1999.

American Society of Pediatric Otolaryngology, Karl Storz Award (for “Contributions in understanding the comparative anatomy and development of the larynx”), awarded to Jeffrey Laitman, 2000.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01357**
Project Title:	**Marine Mammal Acoustic Safety Criteria**
Investigator(s):	**Ridgway, Sam H**
Department or Division:	**Navy Marine Mammal Program**
Performing Organization:	**SPAWAR SSC, San Diego**
Geographic Location of Study:	**San Diego, California**
Marine Mammal Species Involved:	**Dolphin & White whale**
FY 00 Funding Level:	**300,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To use temporary threshold shift (TTS) to quantify the impact of sounds, similar to those emitted from Navy acoustic systems, on marine mammals and to provide scientific data regarding the safest maximum levels to which marine mammals can be exposed without risk of hearing damage.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **Office of Naval Research**

Project Identification Number: **00PR06312**

Project Title: **Nucleic Acid Vaccination in the Bottlenose Dolphin (*Tursiops truncatus)***

Investigator(s): **Ritchie, Branson**

Department or Division: **N/A**

Performing Organization: **University of Georgia Research Foundation Inc.**

Geographic Location of Study:

Marine Mammal Species Involved: **Bottlenose Dolphin**

FY 00 Funding Level: **24,201**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To develop safe, efficacious and low-cost plasmid vaccines against important infectious diseases common in cetaceans; to investigate specific humoral immune responses induced by immunization with a plasmid in *Tursiops truncatus.*

ANNUAL PROGRESS REPORT

Name: Dr. Steven E. Poet/ Dr. Branson Ritchie

Grant Number: N00014-00-1-0561

Title: Nucleic Acid Vaccination in the Bottlenose Dolphin (*Tursiops truncatus*)

Award Period: 4/1/00 to 3/31/01

Objective:
To develop safe, efficacious and low-cost plasmid vaccines against important infectious diseases common in cetaceans; to investigate specific humoral immune responses induced by immunization with a plasmid in *Tursiops truncatus.*

Approach:
The test plasmid, CMV immediate-early enhancer/promoter with the gene for beta-galactosidase, and the negative control plasmid, pCI eukaryotic expression vector lacking a gene are commercially purchased. The plasmids are purified and prepared in phosphate-buffered saline (PBS). Two *Tursiops truncatus* receive either 500 ug of the test plasmid or 500 ug of the negative control plasmid intramuscularly (IM) using ultrasound. On Day 0, the animals will be pre-bled before injected with the plasmids. Blood is collected every two weeks for 16 weeks with repeated vaccinations on weeks 4, 8 and 12. The humoral response is evaluated by an enzyme-linked immunosorbant assay (ELISA) specific for *Tursiops truncatus.*

Accomplishments:
We have completed the analysis of the humoral response of *Tursiops truncatus* to DNA-mediated vaccination using a reporter gene system. The test plasmid animal had a high initial -galactosidase titer prior to the vaccine inoculation. There was not an increase in this titer after vaccination nor throughout the rest of the study. The negative control plasmid did not have high initial -galactosidase titers nor did it produce a humoral response to the plasmid lacking a gene.

Significance:
We have concluded that the -galactosidase reporter gene may not have been appropriate for a vaccination study with cetaceans. This is due to the fact that *Vibrio* sp. contain -galactosidase and *Vibrio* sp. is found in all aquatic systems. Therefore, a different reporter plasmid system is needed to evaluate humoral immune responses to DNA-mediated vaccination in cetaceans.

Work Plan:
The specific objective of the next year's work is to use an engineered plasmid containing a CMV-immediate-early enhancer/promoter with the gene for either hemagglutinin (H) or the fusion (F) protein of canine distemper virus as a reporter system in order to evaluate

the humoral response to DNA-mediated vaccination in cetaceans. If this study proves successful, we will use a plasmid containing either the H or F gene of dolphin morbillivirus as the ultimate safe, efficacious and low-cost plasmid vaccine against this common cetacean disease.

Publications, Abstracts, Technical Reports, Patents, and Awards:
None

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR09362**
Project Title:	**Potential Impacts of Ambient Noise in the Ocean on Marine Mammals**
Investigator(s):	**Roberts, Susan**
Department or Division:	**N/A**
Performing Organization:	**National Academy of Sciences National Research Council**
Geographic Location of Study:	
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**80,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

This National Research Council panel has been asked to outline research needed to evaluate the impacts of ambient noise from various sources (natural, commercial, naval, and acoustic-based ocean research) on marine mammal species, especially in biologically sensitive areas. It will review and identify gaps in existing marine noise databases and recommend research needed to develop a model of ocean noise that incorporates temporal, spatial, and frequency-dependent variables.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01150**
Project Title:	**Investigation of Immune Competence in Navy Marine Mammals: Implications for Health, Viability, and Mission Readiness**
Investigator(s):	**Romano, Tracy**
Department or Division:	**Biology**
Performing Organization:	**Texas A&M University**
Geographic Location of Study:	**SPAWAR SSC San Diego, University of California, San Diego, Texas A&M University**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**196,812**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

To assess the effects of environmental deployment challenges on the autonomic nervous system and immune system of Navy dolphins. Deployment challenges include noise, transport, temperature, environmental pollutants, novel environments, and exposure to wild marine mammal populations. Pharmacological, behavioral, and deployment design techniques will be developed to reduce the impact of environmental deployment challenges on Navy dolphins.

ANNUAL PROGRESS REPORT

Name: Romano

Grant Number: N00014-00-1-0041

Title: Investigation of Immune Competence in Navy Marine Mammals: Implications for Health, Viability, and Mission Readiness

Award Period: 1 October 1999 – 30 September 2004

Objective:
To assess the effects of environmental deployment challenges on the autonomic nervous system and immune system of Navy dolphins. Deployment challenges include noise, transport, temperature, environmental pollutants, novel environments, and exposure to wild marine mammal populations. Pharmacological, behavioral, and deployment design techniques will be developed to reduce the impact of environmental deployment challenges on Navy dolphins.

Approach:
Blood is collected from Navy dolphins and used to standardize available dolphin-specific immunological assays and reagents in our laboratory or is sent to our collaborators for analysis. The assays will provide measures of Navy dolphin immunocompetence and autonomic nervous system activation. Once baseline data is obtained, samples will be collected at time intervals before, during, and after deployment or before, during, and after a specific deployment challenge. For example, samples are being collected before and after noise exposure during the ongoing marine mammal hearing studies at SPAWAR. Data will be analyzed, statistically evaluated and entered into the Navy Marine Mammal Program Database. The potential for prognostic and diagnostic indicators will be evaluated as well as measures developed to reduce the effects of environmental deployment challenges on Navy dolphins.

Accomplishments:
Sample Collection/Processing/Banking We are focusing on collecting multiple baseline samples from Navy dolphins over the first 1.5 - 2 years of the study. The Navy's dolphin population was assessed and a flow chart designed, organizing Navy dolphins into age groups, males and females. Blood was collected, processed, and banked for baseline studies and standardization of assays whenever a dolphin had a routine physical exam or clinical procedure. We have taken opportunities to collect samples from ongoing marine mammal hearing studies, and deployments (e.g. Operation Northern Edge for cold water exposure).

Standardization of Assays ***We have been working with our collaborators in standardizing each assay. Samples have been submitted for immunoglobulin assessment, erysipelas titers, DNA damage, catecholamine and hormone analysis, and cytokine levels. We have been carrying out flow cytometry and the lymphocyte***

proliferation assays as well. Results are pending for some of the assays and/or the data is being analyzed.

Development of a Data Management System We have been consulting with the Navy Marine Mammal Database specialist at SPAWAR to design forms for entry and storage of the neural-immune data. This will enable us to query the immunological data with other information in the database.

Development of dolphin-specific reagents Monoclonal antibody production of beluga-CD4 is in its final stages. We are in the process of fusion and screening for positive clones by flow cytometry. In addition, using our sequence data from beluga CD4 we have isolated, cloned, and sequenced *Tursiops* CD4.

Significance:

The Navy's marine mammal program requires the deployment of Navy dolphins all over the world. During deployments, Navy dolphins undergo challenges, (such as high acoustic levels, transport, temperature changes) that have been shown to activate the autonomic nervous system and cause immunosuppression and increased susceptibility to infectious agents and disease in humans and other mammals. Assessment of the autonomic nervous system and immune system before, during, and after deployment challenges is the first step in understanding how environmental challenges, effect the health of Navy dolphins. Results from our study will also improve our understanding of the effects of environmental challenges on the health of marine mammals in the wild.

Work Plan:

We will continue to obtain blood samples from Navy dolphins for baseline assessment of the autonomic nervous system and immune system. We will also continue to opportunistically collect samples before, during, and after deployment challenges. This includes sample collection at different time points before and after loud sound challenge during hearing studies (TTS) ongoing at SPAWAR. We will continue to standardize available dolphin-specific assays and reagents. Once quality control is established for all assays, samples will be run or submitted routinely. The technology for the dolphin-specific brucella ELISA test that Dr. Garry Adams of Texas A&M University in collaboration with our laboratory at SPAWAR has developed will be transferred to our laboratory for routine monitoring. The Natural killer cell assay will be developed and standardized for dolphins. Samples from operation Northern Edge will be analyzed, and a technical report of the immunological assessment of dolphins after cold water exposure will be written. Samples collected during dolphin hearing studies will be analyzed as a batch and evaluated. An experimental design for the next phase of the study will be devised. The neural-immune portion of the Navy Marine Mammal Program Database will be completed and data entered as it is obtained.

After tremendous effort and time we hope to successfully clone a hybridoma that produces antibodies specific for cetacean CD4. This hybridoma will be characterized. In addition, we will report our findings on the sequence of *Tursiops* CD4. We will begin to isolate, clone, and characterize dolphin CD8 to use in our studies for immune assessment

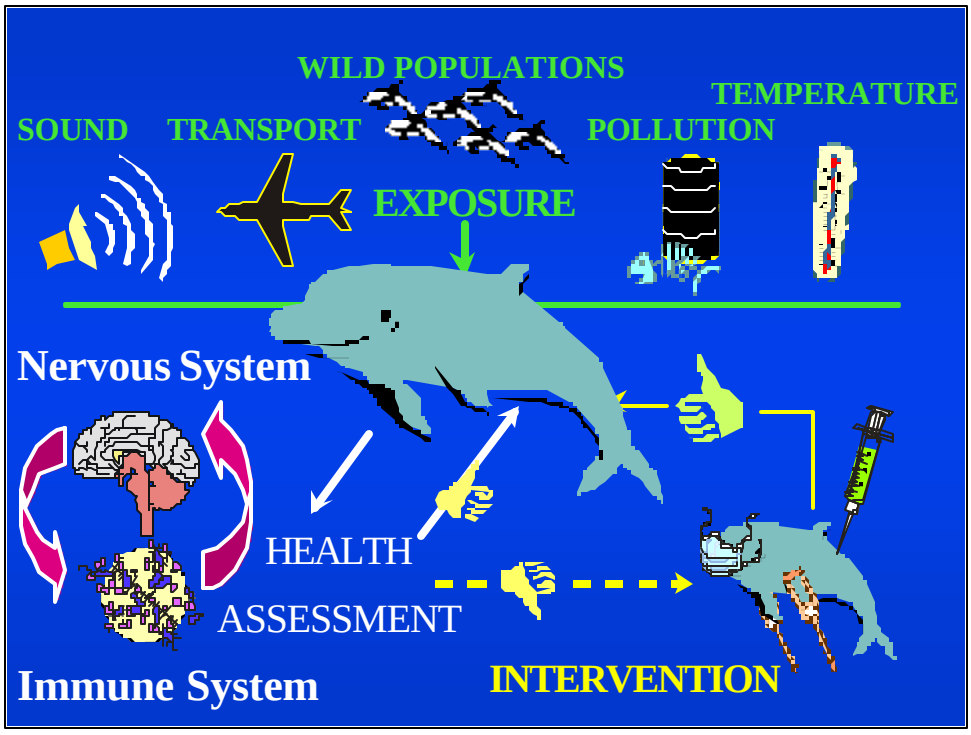
as well as for subsequent use in evaluation of vaccine technology that is related to this study.

Publications, Abstracts, Technical Reports, Patents & Awards:

Romano, T.A., S.H. Ridgway, D.L. Felten, and V. Quaranta (1999), "The Autonomic Nervous System: Effects of Stress and Environment on Marine Mammal Health", Proceedings of the 13th Biennial Conference on the Biology of Marine Mammals, Wailea, Maui, Hawaii, p. 161.

Zabka, T., S. Anders, B. Brendan, T. Romano, S.E. Poet (1999), DNA Vaccines: Assessing the Humoral Immune Response of the Atlantic Bottlenose Dolphin (*Tursiops truncatus*)", Proceedings of the 13th Biennial Conference on the Biology of Marine Mammals, Wailea, Maui, Hawaii, p. 208.

Promotion from Assistant Research Scientist to Associate Research Scientist in the Dept. of Veterinary Anatomy and Public Health at Texas A&M University.



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR08048**
Project Title:	**Equivalence Relations and Cross-Model Transfer as a Tool for Feature Identification in Biosonar Returns**
Investigator(s):	**Schusterman, Ronald**
Department or Division:	**Marine Sciences**
Performing Organization:	**University of California, Santa Cruz**
Geographic Location of Study:	**SPAWARSYSCEN, San Diego**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**125,724**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective of this research is to determine the salient aspects of echoes relative to object features dueing dolphin echolocation performance. The performer will train dolphins to perform sonar-to-visual matching tasks for the purpose of extracting feature-relevant aspects of echoes. These data will be used to inform biomimetic sonar signal processing algorithms.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02582**
Project Title:	**Pinniped bioacoustics: auditory mechanisms, temporary threshold shift, and effects of noise on signal reception.**
Investigator(s):	**Schusterman, Ronald J.**
Department or Division:	**Marine Sciences**
Performing Organization:	**University of California, Santa Cruz**
Geographic Location of Study:	**Long Marine Lab, Santa Cruz, CA**
Marine Mammal Species Involved:	**California sea lion, Northern elephant seal, Harbor seal**
FY 00 Funding Level:	**186,556**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To determine the effects of increasing duration and intensity of noise exposure on levels of TTS in pinnipeds relative to previously obtained values using shorter duration and quieter exposure.

ANNUAL PROGRESS REPORT

Name: Schusterman

Grant Number: N00014-99-1-0164

Title: Pinniped bioacoustics: auditory mechanisms, temporary threshold shift, and effects of noise on signal reception.

Award Period: 1 Dec 98 – 30 Sept 01

Objective:
To determine the effects of increasing duration and intensity of noise exposure on levels of TTS in pinnipeds relative to previously obtained values using shorter duration and quieter exposure.

Approach:
Subjects were one female California sea lion (*Zalophus californianus*), one male harbor seal (*Phoca vitulina*), and one female northern elephant seal (*Mirounga angustirostris*). Underwater hearing thresholds were obtained using behavioral psychophysical techniques. A baseline threshold at either 2500 Hz or 3530 Hz was obtained prior to 25 or 50 minutes exposure to octave-band noise (OBN) centered at 2500 Hz and 95 dB above the mean baseline threshold (sensation level (SL)). A second threshold (exposure) was obtained immediately following noise exposure and a third (recovery) session was conducted 24-h later. Control sequences (same testing and diving pattern, but no noise) were conducted to control for the effects of diving.

Accomplishments:
Results for each of three conditions are summarized below.

95 dB SL 2500 Hz c.f. OBN, 2500 Hz test frequency, 25-min exposure: The harbor seal showed a mean shift of 6.5 dB on eight test sessions and a mean shift of -0.8 dB on four control sessions. The elephant seal showed a mean shift of 2.7 dB on three test sessions and a shift of 0.9 dB on a single control. The sea lion completed two test sessions with a shift of 6.2 dB.

95 dB SL 2500 Hz c.f. OBN, 2500 Hz test frequency, 50-min exposure: The harbor seal showed a mean shift of 12.2 dB on eight test sessions and a mean shift of -0.5 dB on four control sessions. The elephant seal showed a mean shift of 4.3 dB on four test sessions and -1.4 dB on two control sessions. The sea lion showed a mean shift of 9.4 dB on three test sessions and a mean shift of 0.9 dB on two control sessions.

95 dB SL 2500 Hz c.f OBN, 3530 Hz test frequency, 50-min exposure: The harbor seal showed a mean shift of 8.4 dB on experimental sessions and 0.6 dB on control sessions.

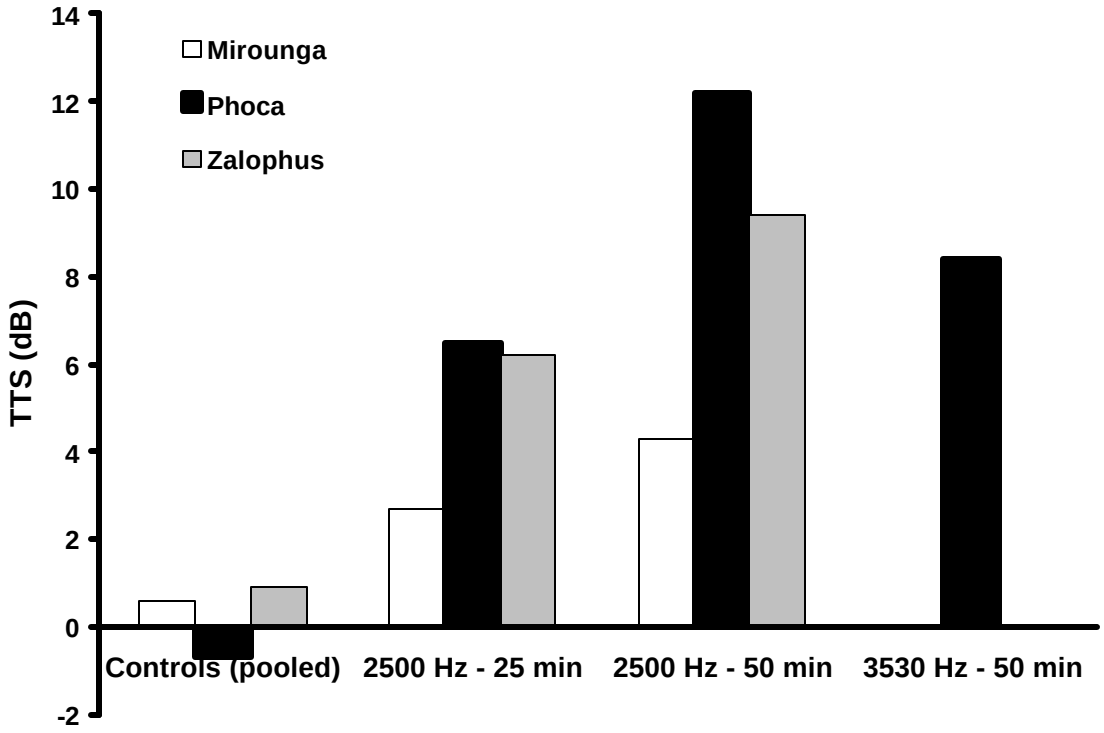
Significance:
Issues involving the effects of noise on free-ranging marine mammals will not be resolved without substantial laboratory data on general hearing capabilities as well as the potential for noise to induce temporary and/or permanent threshold shifts. We have shown, in the current work and our previous studies described in the attached manuscript, that moderate levels of noise can induce threshold shifts ranging from virtually zero to almost 30 dB in pinnipeds. Further, increasing the duration of noise exposure increases the average magnitude of threshold shifts. There appears to be substantial inter and intra-specific variability in the amount of hearing loss following exposure under virtually identical noise regimes. Accordingly, noise exposure standards should be based on what is known about the absolute hearing abilities of individual species rather than on a blanket exposure level criterion that applies to all marine mammals.

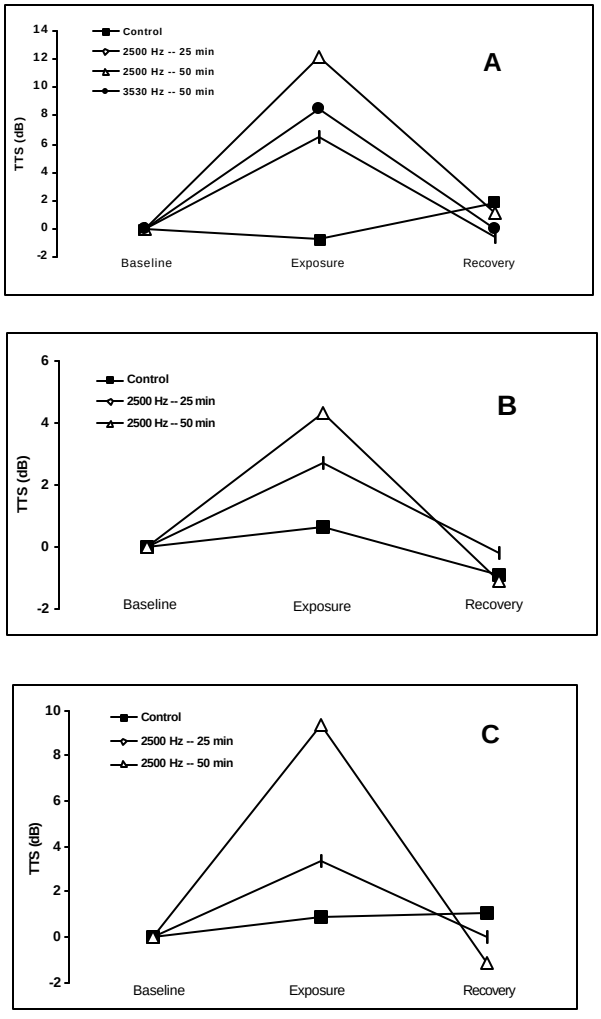
Work Plan:
We will further test the relationship between duration and intensity of noise exposure by increasing the noise level by 10 to 20 dB for exposures of 25 and 50 minutes. Additionally, we will test in air in a hemi-anechoic chamber, so that noise exposure will be continuous, eliminating potential recovery effects caused by repeated surfacing during our present underwater noise exposure schedule. In combination with the acquisition of the test chamber and computer-controlled testing schedules, we will continue work on novel audiometric methods (e.g., method of adjustment) that will allow rapid determination of thresholds following noise exposure (TTS_2) over a range of frequencies. We will obtain critical bandwidth data on all three species using a band widening or band narrowing approach, and compare these estimates to those based on critical ratios. We will continue work in the field at Pt. Lobos State Reserve and at Ano Nuevo Island, measuring ambient noise levels in air and under water, and examining the propagation characteristics of harbor seal vocalizations (under water) and northern elephant seals (in air).

Publications, Abstracts, Technical Reports, Patents & Awards:
Publications:
Schusterman, R.J., Kastak, D, Levenson, D.H., Reichmuth, C.J., and Southall, B.L. (2000). "Why pinnipeds don't echolocate," J. Acoust. Soc. Amer. 107, 2256-2264.
Schusterman, R.J., Reichmuth, C.R., and Kastak, D. (2000). " How animals classify friends and foes," Cur. Dir. Psych. Sci. 9, 1-6.
Levenson, D.H. and Schusterman, R.J. (1999). "Dark adaptation and visual sensitivity in shallow and deep-diving pinnipeds," Mar. Mam. Sci. 15, 1303-1313.
Kastak, D. and Schusterman, R.J. (1999). " In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*)," Can. J. Zool. 77, 1751-1758.
Kastak, D., Schusterman, R.J., Southall, B.L., and Reichmuth, C.J. (1999). "Underwater temporary threshold shift in three species of pinniped," J. Acoust. Soc. Amer. 106, 1142-1148.

Abstracts:
Emery, J. H., Reichmuth, C.R., Schusterman, R.J., and Wilson, E.G. (1999). "Versatile signaling by female harbor seals (*Phoca vitulina*) during the pup attendance period,"

13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 53.
Hayes, S.A., Kumar, A., Costa, D.P., Southall, B.L., Harvey, J.T., Le Boeuf, B.J., and Mellinger, D.K. (1999). "I am harbor seal, hear me roar; a playback experiment," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 79
Holt, M.M., Schusterman, R.J., Kastak, D., and Southall, B.L. (1999). "Pinniped acoustical psychophysics: individual strategies," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 84.
Kastak, D. and Schusterman, R.J. (1999). "Loss of hearing sensitivity with depth in a free diving California sea lion (*Zalophus californianus*)," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 95.
Reichmuth, C.J. and Schusterman, R.J. (1999). "Cognition in California sea lions: the role of different fish reinforcers," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 155.
Schusterman, R.J., Kastak, D., Levenson, D.H., Reichmuth, C.J., and Southall, B.L. (1999). "Why pinnipeds don't echolocate," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 168.
Southall, B.L., Kastak, D., Schusterman, R.J., Reichmuth, C.J., and Grayson, J.W. (1999). "Underwater temporary threshold shift in pinnipeds: the effects of moderate noise levels," 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, Wailea, Hawaii. p. 176.
Kastak, D., Southall, B.L., Schusterman, R.J., and Reichmuth, C.J. (1999). "Temporary threshold shift in pinnipeds induced by octave-band noise in water," 138th Meeting of the Acoustical Society of America, November, 1-5, Columbus, Ohio. p. 2251.





Supporting view graphs (b) shows average TTS values obtained in different test frequency (2500 Hz or 3530 Hz) and noise exposure duration (25 min or 50 min) conditions for (A) a harbor seal (*Phoca vitulina*), (B) a northern elephant seal (*Mirounga angustirostris*), and (C) a California sea lion (*Zalophus californianus*) respectively. "Baseline" thresholds were obtained prior to noise exposure, or prior to diving on control sessions (no noise exposure). "Exposure" thresholds were measured beginning immediately following noise cessation or following diving with no noise. "Recovery" thresholds were measured 24 hrs later. In all noise exposure conditions, 95 dB sensation level, octave-band noise centered at 2500 Hz was used. Each graph shows the average magnitude of threshold shift from baseline values for all sessions conducted in each condition. Note the differences in scale for TTS magnitude between individuals.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**99PR06108**
Project Title:	**Pinniped bioacoustics: new techniques for assessing the effects of anthropogenic noise.**
Investigator(s):	**Schusterman, Ronald J.**
Department or Division:	**Marine Sciences**
Performing Organization:	**University of California, Santa Cruz, CA**
Geographic Location of Study:	**Santa Cruz, CA**
Marine Mammal Species Involved:	**Califonia sea lion, Northern elephant seal, Harbor seal**
FY 00 Funding Level:	**none**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To develop hardware, software, and animal behavioral approaches using instrumentation acquired through this grant to assess the sensory capabilities of marine mammals. To standardize such approaches with the goals of rapidly attaining audiometric data (to assess the effects of noise on hearing); to minimize sound field variations using a diffuse sound field in an anechoic chamber; to employ nonstandard technology to study cross-modal (auditory-visual) perception, problem solving, and effects of noise on perceptual integration. These experiments will be conducted using techniques similar to those employed primarily with sophisticated human and nonhuman primate subjects.

ANNUAL PROGRESS REPORT

Name: Schusterman

Grant Number: N00014-99-1-0686

Title: Pinniped bioacoustics: new techniques for assessing the effects of anthropogenic noise.

Award Period: 30 April 99 – 30 April 01

Objective:
Obtain and design instrumentation for standardized bioacoustic testing of marine mammals

Approach:
To develop hardware, software, and animal behavioral approaches using instrumentation acquired through this grant to assess the sensory capabilities of marine mammals. To standardize such approaches with the goals of rapidly attaining audiometric data (to assess the effects of noise on hearing); to minimize sound field variations using a diffuse sound field in an anechoic chamber; to employ nonstandard technology to study cross-modal (auditory-visual) perception, problem solving, and effects of noise on perceptual integration. These experiments will be conducted using techniques similar to those employed primarily with sophisticated human and nonhuman primate subjects.

Accomplishments:
The software for audiometric testing is in place; the hardware and software for cross-modal and perceptual integration studies is presently under development. The anechoic test chamber has been designed and constructed in modules off-site; we have obtained clearance from the university for on-site installation, which will take place between 15 July and 31 August of this year. Hardware for underwater acoustic testing (effects of particle velocity vs. pressure on the pinniped auditory system) has been obtained and software for sound field control is currently under design.

Significance:
The data on underwater temporary threshold shifts obtained from four pinniped subjects on the ONR contract augmented by this grant (N00014-99-1-0164) must be verified in air, controlling for the amount of sound energy that reaches the inner ear. This verification serves two purposes: 1) it controls for intermittence in noise exposure, which allows for recovery to occur prior to assessment of temporary threshold shift, and 2) it corrects for minor differences in noise exposure regimes between animals based on varying surface and dive intervals. Novel methods of audiometric testing will allow us to obtain rapid threshold estimates across a range of frequencies, allowing a substantial savings in time expended on animal testing and training, a better estimate of threshold shifts occurring within a few minutes of noise exposure, and an idea of the time course of

recovery following TTS. The new underwater phase controlled testing system will allow us to spatially separate acoustic pressure and particle velocity, so that the relative contributions of each to underwater hearing in pinnipeds can be determined.

Work Plan:
We will finalize the setup of hardware and software for audiometric testing, including the installation of the anechoic chamber, modification of testing procedures for cross-modal reception and sound detection. Calibration of in-air and underwater systems will also take place, so that experiments involving sound localization, critical ratios, direct critical bandwidth measurements, touch-screen based visual and auditory simple discriminations and matching-to-sample, auditory-visual cross modal matching, vibrotactile sensitivity, temporary threshold shift, and in-air high frequency sound detection can be conducted within the next year.

Publications, Abstracts, Technical Reports, Patents & Awards:
N/A

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR06096**
Project Title:	**Reagents and Techniques for Vaccine Development and Immune Response Assessment in California Sea Lions**
Investigator(s):	**Stott, Jeffrey**
Department or Division:	**N/A**
Performing Organization:	**University of California, Davis**
Geographic Location of Study:	**Sarasota Bay, CA**
Marine Mammal Species Involved:	**California Sea Lion, Dolphins**
FY 00 Funding Level:	**58,093**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

This research will assist in the development of pathogen-specific DNA vaccines and immunological reagents for stress assessment in California sea lions and dolphins. A suite of reagents and methods for assessing pathogen-specific humoral and cellular immunologic responses in California sea lions will be produced.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**98PR01763**
Project Title:	**Sound Detection by Turtles**
Investigator(s):	**Streeter, Kathy**
Department or Division:	**N/A**
Performing Organization:	**New England Aquarium**
Geographic Location of Study:	**New England Aquarium, MA**
Marine Mammal Species Involved:	**Green Sea Turtle**
FY 00 Funding Level:	**none**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective of this project is to develop a training protocol and experimental design that will allow behavioral testing of a green sea turtle to investigate its hearing capabilities.

ANNUAL PROGRESS REPORT

Name: Streeter

Grant Number: N0001499710198

Title: Sound Detection by Turtles

Award Period: January 1, 1997 - June 30, 2000

Objective:
The objective of this project is to develop a training protocol and experimental design that will allow behavioral testing of a green sea turtle to investigate its hearing capabilities

Approach:
The psychophysical and behavioral methods commonly used to test hearing in other vertebrates were employed. Basically, the green sea turtle, was trained to come to a station, listen for a sound, and then make a behavioral response to indicate signal detection. Standard operant conditioning techniques and positive reinforcement schedules were successfully applied. The method of constant stimuli was applied during test sessions to determine frequency range and thresholds.
The design is based on a go/no go paradigm. The turtle touches the light box to initiate a trial. A light goes on for one second, indicating the start of a trial. If she does not hear a test tone, then she touches the light box again and is rewarded. When a sound trial is initiated, a light and tone go on simultaneously. As always, the light goes out after one second, but the sound continues to broadcast until the response is completed. To indicate that a sound was heard, the turtle swims to and touches the response paddle.

Accomplishments:
This year's efforts focused on completing the development, evaluation, modification, and testing of the fourth experimental design.

The apparatus initially consisted of a light box, one response paddle, and one underwater speaker. Three modifications were made to the experimental set up. During training, the turtle's responses indicated that she did not hear tones when angled slightly away from the speaker. A second speaker was added to insure that the turtle would station between the speakers when initiating a trial, and hear the tones regardless of her position relative to the speaker.

A shield was added that lifts to expose the light box, inviting the turtle to initiate a trial. It is lowered after each trial is completed. This has helped decrease the incidence of false responses resulting from frustration and prospecting between trials.

Finally, the underwater speakers and the response paddle were connected to a pulley system. As a result, only one person is present in the immediate vicinity of the testing

area. This person, who does not know the nature of the trials, is instructed to operate the shield and feed the turtle for correct responses by a person out of the turtle's visual field.

The preliminary data indicates that the turtle hears tones ranging from 100Hz – 500 Hz. Threshold data has been collected on 200Hz and 400Hz. These tests indicate that her threshold for 200Hz is approximately 119 dB (re: 1 micropascal) and for 400Hz it is approximately 121 dB (re: 1 micropascal)

Training and testing during this report period (May 1999 – June 2000) were interrupted for approximately 4 months during the turtle's self-imposed fast. This fasting behavior appears to be related to breeding and migration cycles, and tends to occur on alternate years. However, during this award period, it occurred on consecutive years.

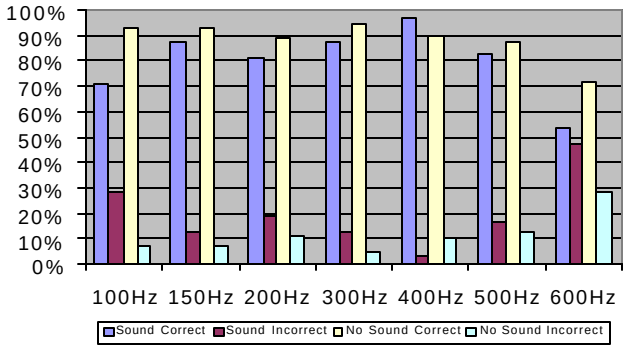
Significance:
All species of sea turtles are either threatened or endangered. Many of the waters ensonified by human-made sounds are also home to endangered turtles. This study provides the first behavioral data on the hearing capabilities of any turtle using psychophysical and behavior methods. The results from this study may provide information that will help fill the gaps in our knowledge about turtle hearing, and help assess the effects of sounds on marine turtles.

Work Plan:
Complete testing threshold levels and begin studying masked thresholds. This will not require any change in design or additional training. Since the turtle is likely to begin fasting again by March or April, testing will be conducting for approximately 7 months.

Publications, Abstracts, Technical Reports, Patents & Awards:
None during this report period.

(VG-2)

Sound Detection by Turtles
Baseline Data Showing Correct Responses by Frequency

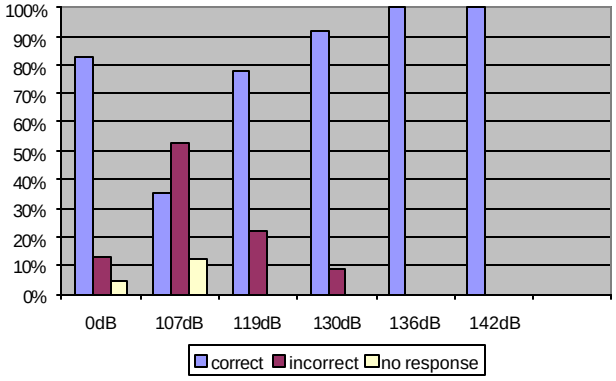


The subject of the study indicated that she heard tones ranging from 100Hz-500Hz. There were harmonics of some concern at 100Hz. At 600Hz the turtle did not appear to hear the tone.

The baseline range of frequencies were tested at dB levels that elicited responses during training sessions. These levels are noted on graph (VG-7).

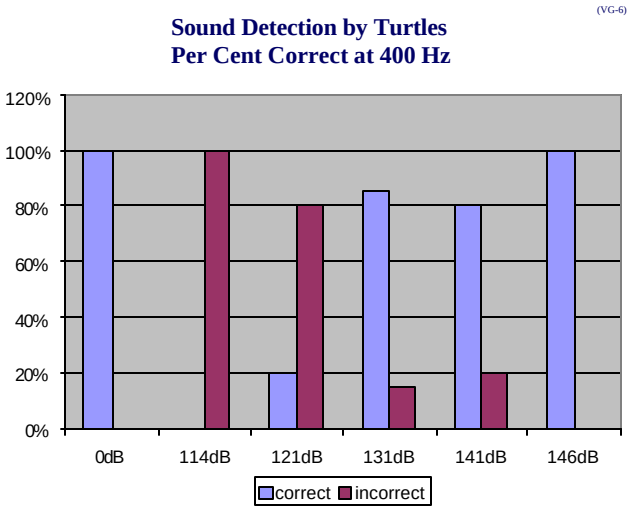
(VG-4)

Sound Detection by Turtles
Percent Correct Response at 200 Hz



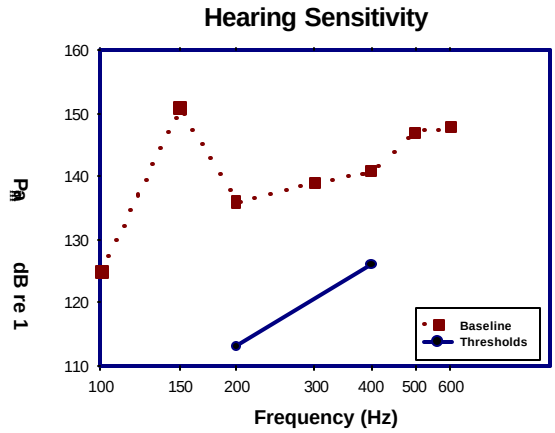
Threshold range was determined using the method of constant stimuli. The data indicate that threshold at 200Hz is between 107dB - 119dB.

(VG-6)



Data indicates that threshold range at 400Hz is between 121Hz - 131Hz.

(VG-8)



The baseline frequencies were tested at dB levels ranging from 125dB at 100Hz to 151dB at 150Hz. Tones above this ranged gradually increased dB level from 136dB at 200 Hz to 148dB at 600Hz.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02606**
Project Title:	**Development and Field Testing of the DTAG for Deep-Diving Odontocetes**
Investigator(s):	**Tyack, Peter L.**
Department or Division:	**Biology**
Performing Organization:	**Woods Hole Oceanographic Institution**
Geographic Location of Study:	**Gulf of Mexico, Mediterranean Sea**
Marine Mammal Species Involved:	**Toothed whales**
FY 00 Funding Level:	**59,604**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The proposed research prepares the methods and field efforts required for experimental studies of reactions of deep diving odontocetes to controlled exposure of sounds in order to verify safe levels of exposure. These tags can measure the acoustic exposure at a whale, while also measuring the vocal and behavioral responses of the whale. The tags are essential for studying the responses of deep diving whales to sound. As a first step in preparing for experiments to study the responses of deep divers, we propose to adapt a digital acoustic recording tag developed with ONR support for shallow-diving whales for use with deep divers. We then plan several field trials one tagging sperm whales in the Gulf of Mexico in collaboration with NMFS and the Minerals Management Service and another continuing collaboration with NATO's SACLANT Center tagging a variety of species in the Mediterranean.

ANNUAL PROGRESS REPORT

Name: Tyack

Grant Number: N00014-99-1-0819

Title: Development and Field Testing of the DTAG for Deep-Diving Odontocetes

Award Period: 5/20/99 – 5/30/01

Objective:
To develop a digital acoustic recording tag suitable for attachment to deep diving toothed whales and to collaborate with the Sirena series of cruises.

Approach:
The proposed research prepares the methods and field efforts required for experimental studies of reactions of deep diving odontocetes to controlled exposure of sounds in order to verify safe levels of exposure. These tags can measure the acoustic exposure at a whale, while also measuring the vocal and behavioral responses of the whale. The tags are essential for studying the responses of deep diving whales to sound. As a first step in preparing for experiments to study the responses of deep divers, we propose to adapt a digital acoustic recording tag developed with ONR support for shallow-diving whales for use with deep divers. We then plan several field trials one tagging sperm whales in the Gulf of Mexico in collaboration with NMFS and the Minerals Management Service and another continuing collaboration with NATO's SACLANT Center tagging a variety of species in the Mediterranean.

Accomplishments:
Tyack took part in the Sirena 99 cruise and planning meetings for Sirena 00. Johnson and Tyack have developed and field tested a digital acoustic recording tag for use with deep-diving marine mammals. The development work included component pressure testing, encapsulation for high pressure, and improvements to the sensor hardware. A new fairing and attachment system was also developed and built. The DTAG ADC hardware and software also required enhancement to accommodate the wide vocalization and hearing frequency range anticipated of odontocetes. We built and calibrated 5 complete tags that will be used during the summer of 00 on a variety of marine mammals.

Significance:
The stranding of beaked whales in the Bahamas this March highlights the importance of determining safe exposure criteria for deep diving marine mammals. The development of a deep diver DTAG and obtaining field experience with tagging them is essential to future experiments to study reactions of deep diving odontocetes to controlled exposure of sounds in order to verify safe levels of exposure. The tags developed under this project were critical for a SERDP proposal that is pending only scientific advisory board review

before funding. This will involve close collaboration with Navy ranges at AUTEC and Onslow Bay.

Work Plan:

This summer we plan to use the deep diver DTAGs on two cruises – one tagging sperm whales in the Gulf of Mexico in collaboration with NMFS and the Minerals Management Service and another continuing collaboration with NATO's SACLANT Center tagging a variety of species in the Mediterranean. These data will be analyzed and prepared for publication, and lessons learned will be used to modify especially the attachment systems.

Publications, Abstracts, Technical Reports, Patents & Awards:

Miller, P.J.O., Biassoni N., Samuels A. and Tyack P.L. 2000. Whale songs lengthen in response to sonar. Nature 405:903

Popper, A.N., H.A. DeFerrari, W.F. Dolphin, P.L. Edds-Walton, G.M. Greve, D. McFadden, P.B. Rhines, S.H. Ridgway, R.M. Seyfarth, S.L. Smith, P.L. Tyack. 2000. Marine mammals and low-frequency sound. National Academy Press.

Tyack, P.L. and Clark C.W. 2000. Communication and acoustic behavior of dolphins and whales. In: Hearing by whales and dolphins. (W. Au, A.S. Popper, and R. Fay eds), Springer Handbook of Auditory Research Series, Springer Verlag, New York.

Johnson, M., P. L. Tyack and D. P. Nowacek. 1999a. A digital acoustic recording tag for measuring the response of marine mammals to sound. In *OCEANS '99*, Seattle.

Johnson, M., P. L. Tyack and D. P. Nowacek. 1999b. A digital acoustic recording tag for measuring the response of marine mammals to sound. In *International Council for the Exploration of the Seas (ICES)*, Stockholm, Sweden.

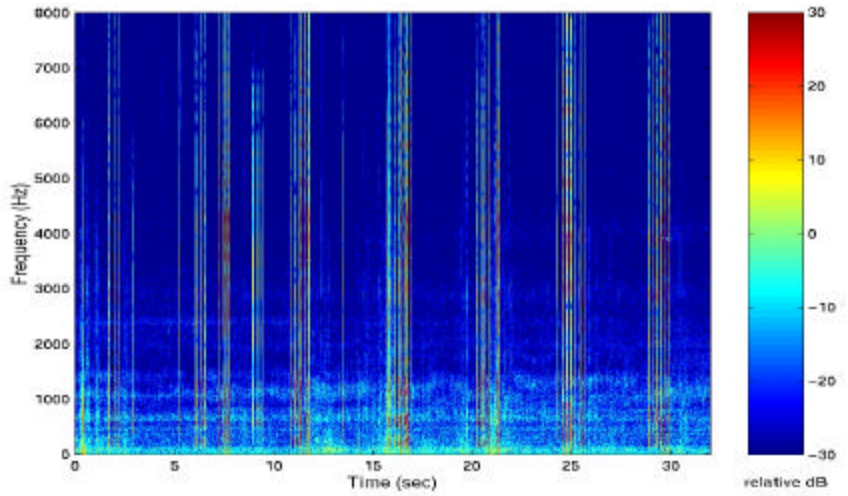
Tyack P. 1999 Playback experiments of loud low frequency sound to singing humpback whales in Hawaiian waters. Whalewatcher 37(1):3-12.

Tyack, P.L. Communication and Cognition. 1999. In: Volume 1, *Biology of Marine Mammals* (J.E. Reynolds III and John R. Twiss Jr. eds), Smithsonian Press, Washington DC.

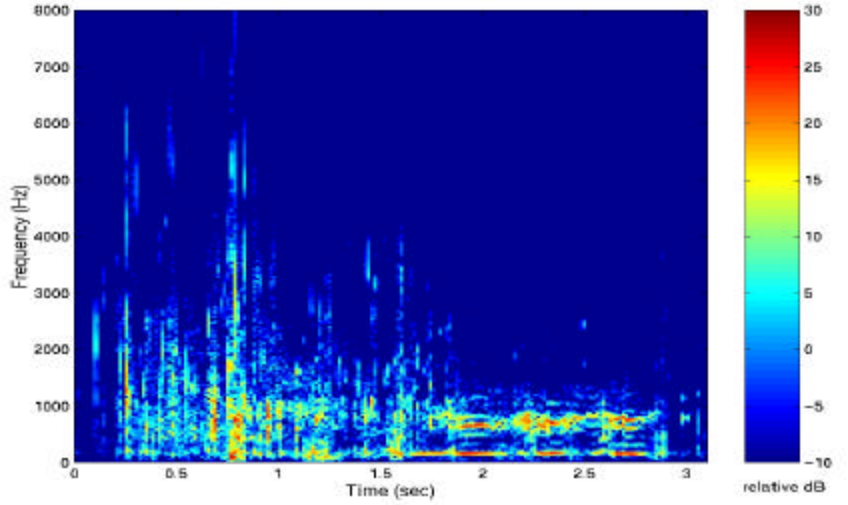
in press Gordon J and P.L. Tyack. Acoustic techniques for studying cetaceans. In: Marine mammals: biology and conservation. (P.G.H. Evans and T. Raga, eds), Plenum Press, London.

in press Gordon J and P.L. Tyack. Sounds and Cetaceans. In: Marine mammals: biology and conservation. (P.G.H. Evans and T. Raga, eds), Plenum Press, London.

Coda Exchanges from Tag between 3 sperm whales



Tag records faint sounds never reported before from sperm whales



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR02622**
Project Title:	**Assessing Risk Factors in Right Whale Vessel Collision Using an Acoustic Recording Tag and Controlled Sound Exposure.**
Investigator(s):	**Tyack, Peter L.**
Department or Division:	**Biology**
Performing Organization:	**Woods Hole Oceanographic Institution**
Geographic Location of Study:	**WHOI, MA**
Marine Mammal Species Involved:	**Right whales**
FY 00 Funding Level:	**60,285**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

To identify risk factors for vessel collision in right whales in order to develop an effective mitigation policy.

ANNUAL PROGRESS REPORT

Name: Tyack

Grant Number: N00014-99-1-0831

Title: Assessing Risk Factors in Right Whale Vessel Collision Using an Acoustic Recording Tag and Controlled Sound Exposure. [I will also discuss a similar project with deep diving cetaceans.

Award Period: 25 May 1999 – 30 September 2000

Objective:
To identify risk factors for vessel collision in right whales in order to develop an effective mitigation policy.

Approach:
We developed an acoustic recording tag that can record external acoustic stimuli that a whale hears, as well as any vocalizations produced by the whale. The tag also contains a three-axis accelerometer to measure movement and a three-axis magnetometer to measure the orientation of the whale along with a pressure sensor to measure depth of dive. These response measures are sampled at much higher rates (approx 30 samples/second) than traditional tags. This rapid sampling enables much more detailed analysis of behavioral responses, such as fluke rate, rolling etc than is possible with tradition TDRs. We plan to study risk factors for vessel collision by conducting controlled exposures of noise to tagged whales. After baseline data are collected, a playback vessel approaches the whale, playing back vessel noise. A right whale vocalization that attracts adult males is also played back to test the ability of whale subjects to detect and respond to a faint acoustic signal.

Accomplishments:
Six of seven tag deployment attempts were successful. One animal removed the suction cup tag, but all others showed no reaction to the tagging and displayed a very regular dive pattern, similar in consistency to that exhibited by other whales. All other tagging attachments occurred without incident and the DTAG collected its full complement of data. The data are available on our 'DTAG website' (http://ragged.whoi.edu), have been presented at two scientific meetings (Johnson *et al*. 1999b; Johnson *et al*. 1999a), and are being prepared for publication. A draft report on the implications of buoyancy on the dive patterns of right whales is appended to this synopsis. The sounds of a variety of vessels are obvious on many of the records from tagged whales, but only one animal, #1306, was exposed to controlled sound exposures during operations with the DTAG. One hour after the DTAG was attached to #1306 the playback vessel started a slow approach (~3 kts.) toward the tagged whale, which was being followed by observers on a yacht. The sound stimulus played to the whale was pre-recorded vessel noise, specifically the approach and pass of one of Irving Oil Inc.'s very large crude carriers. During the playback approach

the focal whale joined with two other whales, i.e. the three whales were now within 500 m of each other. No visible response to the playback was observed from either the observation vessel or in the DTAG data.

Significance:
This project has revealed a dive pattern in buoyant right whales that is very different from all other marine mammals studies (Williams et al. 2000). Right whales swim hard to descend, but glide on ascent. This project is also the first to integrate tagging with controlled exposures of noise. The techniques and personnel developed for this will be equally useful for working with deep divers such as beaked whales. Two results are significant for assessing risk of vessel collision. The lack of obvious responses to uncontrolled vessel approach or the one controlled approach have led us to add a second sound stimulus designed to be more likely to alert the whale, and possibly evoke an avoidance reaction. If this stimulus more reliably evokes avoidance, then this would suggest that a low-level non-aversive warning signal may help reduce the risk of collision, as was suggested by the Interagency Workshop on the use of active acoustics to reduce right whale mortalities and injuries from ship strikes. Second, our dive data show that right whales are so buoyant that they must swim hard when diving, but can glide on ascent, and this ascent is more rapid than descent. If right whales passively glide to the surface, then they may be less able to avoid an oncoming vessel than other cetaceans, which actively swim on ascent. Hydrodynamic studies suggest that a passive whale is much more vulnerable as it surfaces than when it is already at the surface, where the surface wave may move the whale away from the vessel. This suggests that surfacing right whales may be at particular risk of collision.

Work Plan:
The ONR supported results from last summer stimulated the National Marine Fisheries Service to fund a continuation of this project for this coming summer. This summer, with funding from NOAA NMFS via CICOR, we are planning to DTAG whales then expose them to either ship noise, an approach from an actual large vessel, or playback of natural sounds. We plan to deploy DTAGs on right whales in the Bay of Fundy during July – August 2000. Tagged whales will be exposed to controlled exposures of vessel noise and a different stimulus designed to alert whales during approaches of the tagged whale. We will also test the capabilities of subjects to detect and respond to fainter stimuli by playing back a right whale vocalization that elicits strong approach reactions in adult males. We are writing up analyses of dive behavior from previously tagged whales.

Publications, Abstracts, Technical Reports, Patents & Awards:
Miller, P.J.O., Biassoni N., Samuels A. and Tyack P.L. 2000. Whale songs lengthen in response to sonar. Nature 405:903

Popper, A.N., H.A. DeFerrari, W.F. Dolphin, P.L. Edds-Walton, G.M. Greve, D. McFadden, P.B. Rhines, S.H. Ridgway, R.M. Seyfarth, S.L. Smith, P.L. Tyack. 2000. Marine mammals and low-frequency sound. National Academy Press.

Tyack, P.L. and Clark C.W. 2000. Communication and acoustic behavior of dolphins and whales. In: Hearing by whales and dolphins. (W. Au, A.S. Popper, and R. Fay eds), Springer Handbook of Auditory Research Series, Springer Verlag, New York.

Johnson, M., P. L. Tyack and D. P. Nowacek. 1999a. A digital acoustic recording tag for measuring the response of marine mammals to sound. In *OCEANS '99*, Seattle.

Johnson, M., P. L. Tyack and D. P. Nowacek. 1999b. A digital acoustic recording tag for measuring the response of marine mammals to sound. In *International Council for the Exploration of the Seas (ICES)*, Stockholm, Sweden.

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Tyack, P.L. Communication and Cognition. 1999. In: Volume 1, *Biology of Marine Mammals* (J.E. Reynolds III and John R. Twiss Jr. eds), Smithsonian Press, Washington DC.

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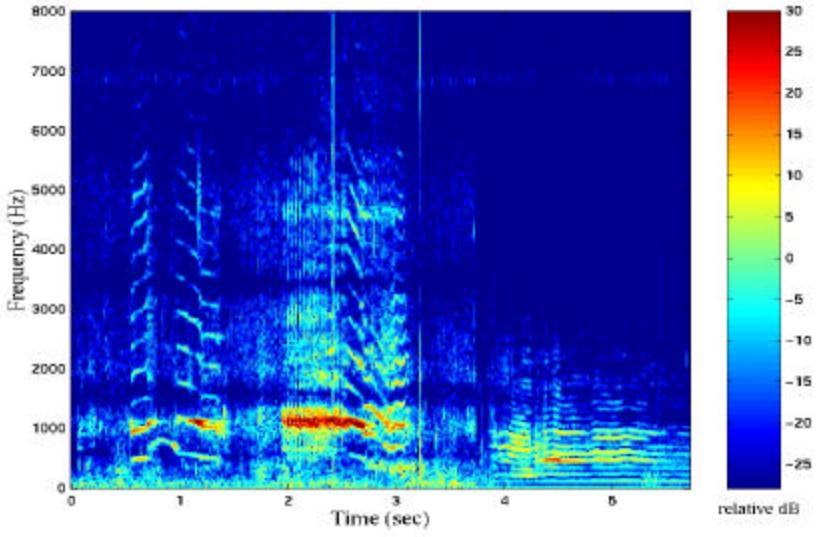
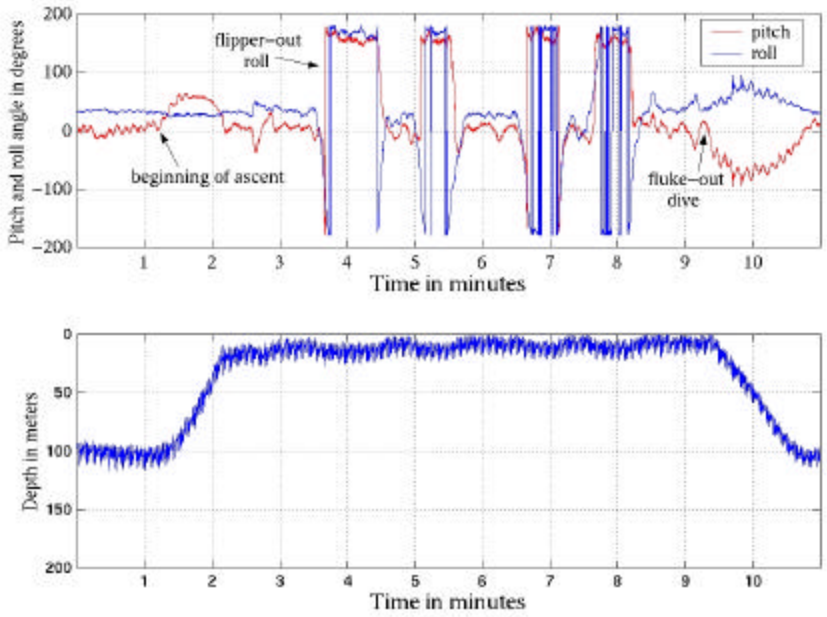
in press Gordon J and P.L. Tyack. Sounds and Cetaceans. In: Marine mammals: biology and conservation. (P.G.H. Evans and T. Raga, eds), Plenum Press, London.

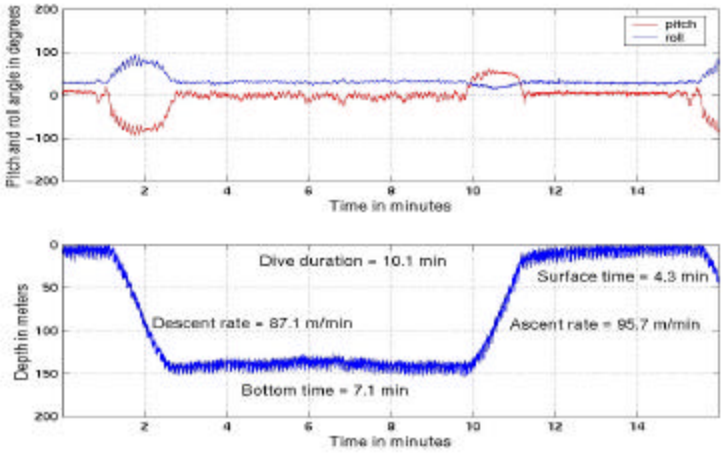
Right whale vocalizations recorded with DTAG



Measuring postural behaviors with pitch and roll sensors



Right whale 99-223: One dive cycle



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR06292**
Project Title:	**Continued Investigations of Plasmid Gene Expression in Marine Mammals**
Investigator(s):	**Van Bonn, William**
Department or Division:	**Biosciences D35**
Performing Organization:	**Space and Naval Warfare Systems Center, San Diego**
Geographic Location of Study:	**San Diego Bay, CA**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**49,500**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To develop knowledge, methodologies, and reagents required to apply revolutionary nucleic acid transfection technology to Navy working marine mammals. The products will lead to the development and application of specific DNA vaccines and immunomodulating plasmids for the protection of Navy marine mammals.

ANNUAL PROGRESS REPORT

Name: Van Bonn

Grant Number: N00014-00-W-X21016

Title: Continued Investigations of Plasmid Gene Expression in Marine Mammals

Award Period: 01 January 2000 – 31 December 2000

Objective:
To develop knowledge, methodologies, and reagents required to apply revolutionary nucleic acid transfection technology to Navy working marine mammals. The products will lead to the development and application of specific DNA vaccines and immunomodulating plasmids for the protection of Navy marine mammals.

Approach:
The approach includes five task areas. Evaluate the ability of a 500 µg dose of a β galactosidase gene containing plasmid, injected intramuscularly, to induce a measurable immune response in mature bottlenose dolphins. Survey random Navy dolphins for naturally occurring antibodies that cross- react with ß-galactosidase. Continue development of a cell mediated immune response assay in the bottlenose dolphin. Initiate investigations into alternate routes and methods of plasmid vaccine administration in bottlenose dolphins. Initiate investigations into specific plasmid sequences expected to be protective against known infectious threats to Navy marine mammals, or to enhance the immune response of plasmid delivered gene products.

Accomplishments:
The trial with a plasmid encoding Beta-galactosidase has been completed. The study animal received four doses of 500 µg intramuscularly near the superficial cervical lymph node. A control animal received four doses of an "empty" vector. Blood was collected at bi-weekly intervals for ELISA assays for circulating anti-Beta-gal antibodies and cellular response assays under development. The ELISA assays for anti-Beta-gal antibodies have been completed.

A student technician has been hired to work part-time on the cellular assay. The student has been trained in techniques that will be used for follow on efforts including, separation of lymphocytes from dolphin whole blood, cryopreservation techniques, proper thawing, PCR/ RT PCR, DNA cloning and sequencing, etc.

Efforts are ongoing to design and clone a vector encoding Canine Distemper Virus, a virus closely related to Dolphin morbillivirus. This construct will be used as an alternative reporter gene to avoid high "background" titers to Beta-galactosidase we have seen in dolphins. This construct may also provide some protection to the animals against the related Dolphin morbillivirus and will be suggested for use in the sea lions as well.

Sea lion immunoglobulin has been purified from serum and used to immunize mice for production of monoclonal antibodies.

Significance:
Navy animals live and work in the open-ocean environment. They deploy regularly to waters distant from their home enclosures in San Diego. As a consequence, the animals may be exposed to foreign organisms and potential health threats. Moreover, there is evidence that these animals have not been exposed to some of the known causes of disease and death in wild marine mammals such as morbilliviruses and therefore have no "natural immunity". Outbreaks of disease in an unprotected population can be devastating.

It is often postulated that man-made devices will one day match the capabilities of animal sonar systems. That day has not come. Until it does, animal sonar systems, specifically highly trained Navy Atlantic bottlenose dolphins remain the most efficient, cost-effective, rapidly deployable means of target detection in the MCM environment.

Additionally the techniques, reagents and assays developed under this effort will allow for the design and implementation of non-specific enhancement of immune responses to environmental challenges encountered during deployment of marine mammal systems. Other potential advances include the development of nucleic acid "markers" uniquely identifying Navy animals. We anticipate the products of this effort to be of great interest to all organizations housing marine mammals and those involved in the treatment and rehabilitation of stranded marine mammals worldwide. In addition, the experiments conducted under this project will provide valuable novel animal models for the application of nucleic acid transfection techniques. These models will serve as source data for transfection experiments in other species including humans

Work Plan:
If either humoral or cellular responses are detected in the Beta-gal experiment, the experiment will be repeated in five additional study and five additional control animals to examine individual variation. If no humoral, cellular or memory response can be detected efforts will shift to focus on alternate routes and methods of plasmid administration. In either case, because we have detected high levels of interfering naturally occurring anti-Beta-gal antibodies, we will utilize an alternative plasmid as our reporter gene delivery vector. This alternate plasmid will encode for Canine Distemper virus genes, closely related to the Dolphin and Phocine morbilliviruses. These genes will be cloned and inserted into the same plasmid vector used to deliver the Beta-gal gene. In addition, we will continue efforts in development of a plasmid construct including cloned genes from Dolphin morbillivirus inserted in a proven vector provided by Vical, Inc. of San Diego.

We will continue analyses of existing clinical database records to determine the known infectious disease threats to marine mammals and rank order them by risk to Navy animals. This will direct future plasmid construct development. We will also continue microscopic anatomical investigations into the possibility of alternative routes of plasmid administration to marine mammals such as intradermal or oral.

Publications, Abstracts, Technical Reports, Patents & Awards:

(2000) Brownell, R. L. Jr., B. E. Curry, W. Van Bonn, and S.H. Ridgway. Conservation Conundrum. Science. 288-2319-2320.

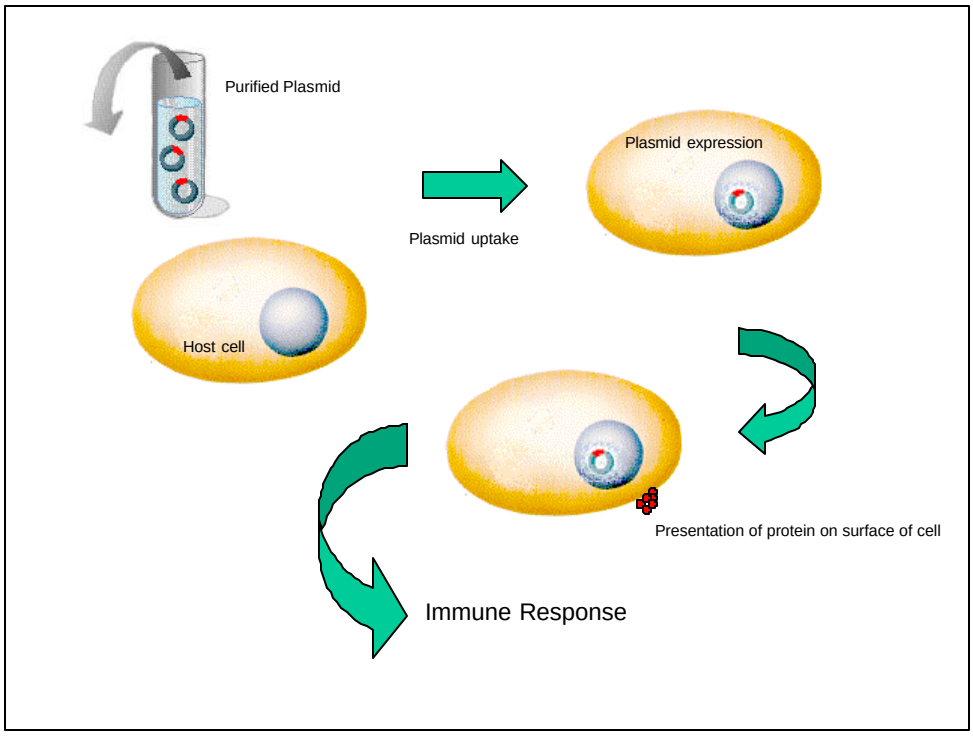
Romano, T.A., S.H. Ridgway, D.L. Felten, and V. Quaranta (1999), "The Autonomic Nervous System: Effects of Stress and Environment on Marine Mammal Health", Proceedings of the 13th Biennial Conference on the Biology of Marine Mammals, Wailea, Maui, Hawaii, p. 161.

Schock, T.B., S.A. Smith, K.E. Howard, T.S. Zabka, and S.E. Poet. 2000. Evaluation of the humoral immune response to DNA vaccination in tilapia (*Oreochromis niloticus)*. Proceeding of the 31st Annual Conference of the International Association for Aquatic Animal Medicine. (publication in progress).

Sherril, J., T.B. Schock, J.L. Dunn, D.J. St. Aubin, V.V. Burnley, and S.E. Poet. 2000. Humoral immune response to DNA-mediated immunization in African black-footed penguins (*Spheniscus demersus).* Journal of Zoo and Wildlife Medicine (publication accepted).

Zabka, T., S. Anders, B. Brendan, T. Romano, S.E. Poet (1999), DNA Vaccines: Assessing the Humoral Immune Response of the Atlantic Bottlenose Dolphin (*Tursiops truncatus*)", Proceedings of the 13th Biennial Conference on the Biology of Marine Mammals, Wailea, Maui, Hawaii, p. 208.

Illustrated here is the concept of transfection technology as we intend to apply it in a preventive medicine program.



PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR01649**
Project Title:	**Aquatic Propulsion and Maneuverability: Mechanics and Neural Control of Fin Locomotion in Fishes**
Investigator(s):	**Westneat, Mark W.**
Department or Division:	**Zoology**
Performing Organization:	**Field Museum of Natural History**
Geographic Location of Study:	**Field Museum of Natural History, Chicago, IL**
Marine Mammal Species Involved:	**Fish**
FY 00 Funding Level:	**125,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

Pectoral fins in fishes vary in shape and mechanical performance, are efficient and quiet, and allow high maneuverability to the animals that use them. The goal of this research is to understand the neurological, mechanical, and hydrodynamic basis of pectoral fin locomotion and how design variation affects mechanical performance. An engineering knowledge of organic design will provide new applications for propulsion technology.

ANNUAL PROGRESS REPORT

Name: Westneat

Grant Number: N00014-99-1-0184

Title: Aquatic Propulsion and Maneuverability: Mechanics and Neural Control of Fin Locomotion in Fishes

Award Period: 10 December 1998 – 10 December 2002

Objective:
Pectoral fins in fishes vary in shape and mechanical performance, are efficient and quiet, and allow high maneuverability to the animals that use them. The goal of this research is to understand the neurological, mechanical, and hydrodynamic basis of pectoral fin locomotion and how design variation affects mechanical performance. An engineering knowledge of organic design will provide new applications for propulsion technology.

Approach:
Kinematics. Two high-speed digital video cameras are used to film fish swimming in a flow tank (for steady swimming sequences) or in still water (for maneuvering sequences). Motor control. For recording muscle activity, bipolar, fine wire electrodes are implanted in three lateral muscles and three medial muscles that control the fin. EMG data shows us how the nervous control of fin muscles produces complex propulsion behavior in fishes. Mechanical design. Fin shapes range from wing-like to paddle-shaped, and these forms appear to be used in different ways to generate thrust. We are analyzing fin shape using a morphometric approach that will allow calculation of variables that determine thrust forces.

Hydrodynamics. We are collaborating with Dr. William Sandberg (Naval Research Laboratories) who is using our kinematic and body shape data to model the unsteady fluid dynamics of paired, oscillating fins using computational fluid dynamics (CFD). Mechanical modeling. We use computer models to estimate different sources of force generation on the oscillating fin and to investigate the effects of stroke frequency, amplitude, stroke plane angle and fin shape on the total force, power and mechanical efficiency of a fin stroke.

Accomplishments:
Kinematic data on both steady swimming and maneuvers were completed for 4 species. In addition, swimming performance data (critical swimming speed) have been collected for 8 species. Fin shape morphometrics has been collected for all 180 species of labrid fishes in the far Southwestern Pacific. Kinematics, performance, and fin shape data are being analyzed for a series of papers (2 now in manuscript) correlating morphology and behavior in fishes that locomote in different ways. Detailed 3D data on fin motion will supply key parameters for development of model fins and prototype vehicles.

Computer simulations have been completed for the two major types of fins: drag-based, high thrust fins that are good for maneuvering and high-aspect ratio fins for efficient thrust over distance. These results have been published (Walker and Westneat, In Press) and suggest key questions for our motor-driven fin modeling research.

The 16-channel neural recording system has been developed, tested and is now being used to collect data on muscle activity in numerous forms of locomotion: pectoral fins in fishes, fast-start escapes in fishes, S-start thrusts during feeding in fishes, and the motor control of the hindlimbs of turtles during both aquatic and terrestrial locomotion.

The mechanical design of fishes has been quantified for both pectoral fin mechanisms and for the locomotor systems of mackerels and tunas. An anatomical paper is being developed in which we propose the mechanics of fin motion as it is driven by muscles, and forces are translated through tendons to cause fin rotation. Previous work on tuna morphology was recently expanded for a book chapter (Westneat and Wainwright, In Press).

Significance:

Scientific impact:

We are publishing quantitative data on behavior and fin shape for a mode of locomotion that is dominant among fishes in complex 3D habitats such as coral reefs. This data adds greatly to our knowledge of the basic ecology of these animals and contributes to our understanding of coral reef diversity.

Our integrative approach to morphology, neural control, and behavior is revealing central principles of locomotor design and function in fishes.

Modeling and computer simulations provide biological predictions that are tested with data on living fishes. We can assess the number of designs and behaviors that fishes use out of the universe of possible designs and begin to understand patterns of diversity, contraint, and evolution in this system.

Naval impact:

Fin-based locomotion in fishes and other aquatic vertebrates is the best model to imitate for human-designed AUVs that need maneuverability. This research is providing the data necessary to mimic the design, control, and behavior of fishes that show spectacular maneuverability.

The 2 collaborations (with Sandberg and Kato) currently represent our best chance for direct application of our data to projects on vehicle design. Both collaborations require information on body shape, fin shape, and behavior that we are able to provide.

Work Plan:

Kinematics, fin morphology, and performance (critical swimming speed) data will be collected from 10 additional species of labrid fishes that span the range of body shape, fin

shape, and maneuverability found in the family. This will enhance our perspective on locomotor strategies in the group, provide behavioral data for hydrodynamics and AUV prototype designs, and provide information for an evolutionary analysis of labriform locomotion.

Neuromotor patterns will be recorded from 3 species during both steady swimming and maneuvers. EMG data will be recorded from all 6 major fin muscles on both sides. We will address questions of asymmetry of neural control during turns, and assess patterns of EMG in fishes with different fin shapes and locomotor strategies. It should also be noted that the 16-channel EMG equipment will directly contribute to a large number of projects on neural control of locomotion, including pectoral fins in fishes, fast-start escapes in fishes, S-start thrusts during feeding in fishes, and the motor control of turtles during both aquatic and terrestrial locomotion.

Increased technology transfer efforts in the coming year will include the publication of the first CFD analysis in collaboration with Sandberg's group, the first model fin testing in our own lab, and the development of the exciting collaboration with Naomi Kato and the Japanese fin robotics group.

Publications, Abstracts, Technical Reports, Patents & Awards:

Publications directly related to ONR grant:

Walker, J. A. and M. W. Westneat. 2000. Mechanical performance of aquatic rowing and flying. Proc. Roy. Soc. Lond. (Ser. B). In Press.

Westneat, M. W. and S. A. Wainwright. 2000. Mechanical Design in Tunas: Muscle, Tendon, and Bone. In Block, B, and Stevens, D. Fish Physiology: Comparative Physiology of Tunas. Academic Press. In Press.

Walker, J. A. 2000. Maneuvering performance and fin locomotion in boxfishes. J. Exp. Biol. In Press.

Westneat, M. W. and J. A. Walker. 1999. Mechanical design of fin propulsion: kinematics, hydrodynamics, morphology and motor control of pectoral fin swimming. Proceedings of the Conference on Unmanned, Untethered Submersible Technology. Autonomous Underwater Systems Institute, Durham, NH.

Rosenberger, L. J. and M. W. Westneat. 1999. Functional morphology of undulatory pectoral fin locomotion in the stingray, *Taeniura lymma*. Journal of Experimental Biology 202, 3523-3539.

Other publications supported in part by ONR funding:

Westneat, M. W. 2000. The Western Central Atlantic: FAO species identification sheets for fishery purposes. Family Labridae. Food and Agriculture Organization of the United Nations. In Press.

Westneat, M. W. 2000. Functional Morphology and Physiology: Comparative Methods. Encyclopedia of Life Sciences Macmillan Reference Ltd. In Press.

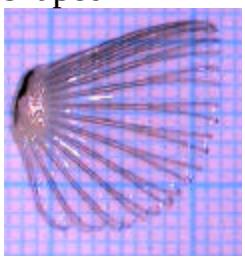
Westneat, M. W. 2000. Vertebrate Functional Morphology and Physiology. Encyclopedia of Life Sciences Macmillan Reference Ltd. In Press.

Westneat, M. W. 2000. Feeding in Fishes. Encyclopedia of Life Sciences Macmillan Reference Ltd. In Press.

Alfaro, M. E., and M. W. Westneat. 1999. Biomechanics of parrotfish feeding: motor patterns of the herbivorous bite. Brain, Behavior and Evolution 54:205-222.

Pectoral Fin Shapes

Paddle- shaped

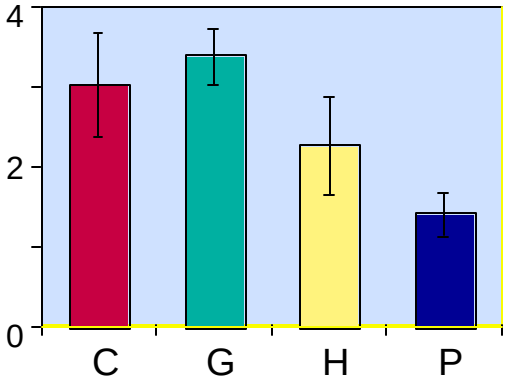


Cheilinus trilobatus *Labrichthys unilineata*

Wing- shaped

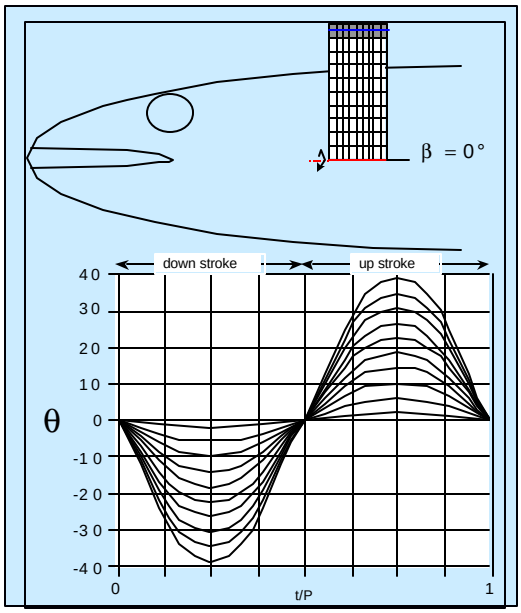
Scarus altipinnis *Gomphosus varius*

Aspect ratio- 4 species



Conclusion: Fin shapes are variable, and are correlated with locomotor mode, fin motion, degree of maneuverability, and swimming performance (critical swimming speed). Mimicry of fin shapes and properties is suggested for AUVs.

Hydrodynamic modeling of flapping stroke



Dynamic model of oscillating fin during high-efficiency flapping.

Upper: Fin dynamically twists around the pitching axis (here pitch axis =0).

Lower: Pitch axis for the ten blade elements throughout the stroke cycle.

Model uses kinematics to calculate mechanical efficiency and mean thrust of paired rowing or flapping appendages.

From Walker and Westneat 2000- Proc Roy Soc In Press

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR06299**
Project Title:	**Marine Mammals as Models for Cost Efficient AUVs: Performance Specifications of Oscillating Hydrofoils**
Investigator(s):	**Williams, Terrie M.**
Department or Division:	**Biology**
Performing Organization:	**University of California, Santa Cruz**
Geographic Location of Study:	**University of California, Santa Cruz, CA**
Marine Mammal Species Involved:	**Bottlenose Dolphin**
FY 00 Funding Level:	**50,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

To determine the efficiency and performance limitations of oscillating hydrofoils used in nature; to develop a summary guide comparing the operational speeds, frequencies, stroke costs, efficiencies, minimum range costs of oscillating hydrofoils used by marine mammals.

ANNUAL PROGRESS REPORT

Name: Williams

Grant Number: N00014-00-1-0761

Title: Marine Mammals as Models for Cost Efficient AUVs: Performance Specifications of Oscillating Hydrofoils

Award Period: 10-May-2000 to 30-April-2003

Objective:
To determine the efficiency and performance limitations of oscillating hydrofoils used in nature; to develop a summary guide comparing the operational speeds, frequencies, stroke costs, efficiencies, minimum range costs of oscillating hydrofoils used by marine mammals.

Approach:
New data obtained in laboratory and field experiments are compared for a variety of marine mammals using different forms of oscillating hydrofoils for propulsion. Laboratory tests utilize bottlenose dolphins (dorso-vental fluke hydrofoil) trained to push against a load cell. Oxygen consumption, kinematics, blubber deformation and force production are measured simultaneously. Propulsive efficiency and the cost per stroke are calculated from the data. These results are compared to concurrent data obtained from free ranging diving phocid seals (lateral undulating hydrofoil) as well as previous measurements made for otariids (fore flipper hydrofoil) and sea otters (paddle propulsion).

Accomplishments:
We have successively completed the free ranging studies on diving dolphins and phocid seals. Comparative data was obtained for diving blue whales and the results for four species published in Science (vol. 288, 2000). An important factor contributing to swimming efficiency in both small (150 kg) and large (100 tons) animals was the ability to incorporate prolonged gliding periods during vertical (diving) movements. This led to a 10 –50% savings in energetic costs during submergence and enabled the animals to prolong underwater performance.

Experiments with dolphins pushing against a load cell have characterized routine preferences of hydrofoil operation (average load = 50 - 60 kg, average frequency = 1.0 – 1.5 Hz). Ongoing experiments focus on the kinematic changes required for performing outside of this preferred range.

Significance:
The kinematic analyses of mammals performing deep (> 100 m) dives have demonstrated a major factor leading to overall propulsive efficiency regardless of hydrofoil placement on the body. These results should provide engineers with new operational specifications

to maximize the efficiency and performance capabilities of novel autonomous underwater vehicles.

Work Plan:
The primary objective of next year's work will be to determine the relationship between the energetics and mechanics of oscillating hydrofoils. Data will be compared for marine mammals using three types of oscillating hydrofoils, 1) forward placement hydrofoils as characterized by otariids, 2) hind placement, lateral hydrofoils as in phocid seals, and 3) hind placement, dorso-ventral hydrofoils as used by cetaceans and otters.

Oxygen consumption and kinematic measurements have been collected for sea lions and sea otters swimming in a flume, and for seals diving to depth. During the next 12 months these data will be synthesized to assess the cost per stroke and propeller efficiency for each type of hydrofoil. Similar measurements are currently being made for dolphins pushing against a load cell. Once completed stroking costs and propeller efficiency will also be determined for these animals, and a comparative summary for engineers initiated.

Publications, Abstracts, Technical Reports, Patents & Awards:
Williams, T.M., Davis, R.W., Fuiman, L.A., Francis, J., LeBoeuf, B., Horning, M., Calambokidis, J. and Croll, D.A. 2000. Sink or swim strategies for cost efficient diving by marine mammals. Science 288: 133-136.

Williams, T.M. Haun, J.E., and Friedl, W.A. 1999. The diving physiology of Bottlenose Dolphins, (*Tursiops truncatus*) I. Balancing the demands of exercise for energy conservation at depth. J. Exp. Biol. 202: 2739-2748.

Skrovan, R.C., Williams, T.M., Berry, P.S., Moore, P.W., and Davis, R.W. 1999. The diving physiology of Bottlenose Dolphins, (*Tursiops truncatus*) II. Biomechanics and changes in buoyancy with depth. J. Exp. Biol. 202: 2749-2761.

Williams, T.M., Noren, D., Berry, P., Estes, J.A., Allison, C., and Kirtland, J. 1999. The diving physiology of Bottlenose Dolphins, (*Tursiops truncatus*) II. Thermoregulation at depth. J. Exp. Biol. 202: 2763-2769.

Davis, R.W., Fuiman, L.A., Williams, T.M., Collier, S.O., Hagey, W.P., Kanatous, S.B., Kohin, S., and Horning, M. 1999. Hunting behavior of a marine mammal beneath the Antarctic sea ice. Science 283: 993-996.

Noren, D.P., Williams, T.M., Berry, P., and Butler, E. 1999. Thermoregulation during swimming and diving in Bottlenose Dolphins, *Tursiops Truncatus*. J. Comparative Physiology B 169: 93-99.

Costa, D.P., and Williams, T.M. 1999. Marine mammal energetics. In: *Textbook of Marine Mammals*, J.E. Reynolds III and S.A. Rommel, eds. Smithsonian Institution Press, pp. 176-217.

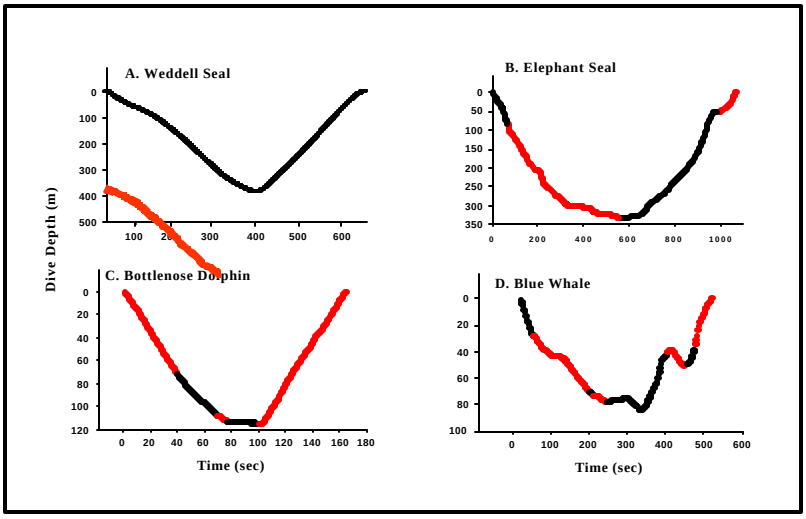
Williams, T.M. 1999. The evolution of cost efficient swimming in marine mammals: Limits to energetic optimization. Phil. Trans. R. Soc. Lond. B 354, 193-201.

Abstracts
Williams, T.M. 1999. Sink or swim strategies for low cost diving in marine mammals. American Zoologist 39(5): 4A.

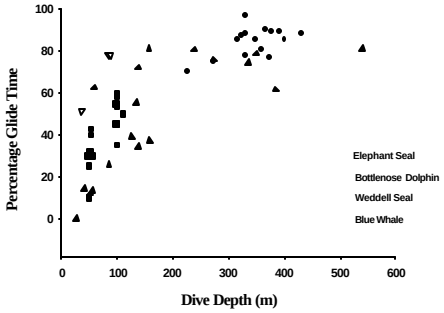
Williams, T.M. and Hurley, W.C. 1999. Batteries not included: Marine mammal strategies for cost efficient underwater performance. Proceedings of the 11th International Symposium on Unmanned Untethered Submersible Technology (99-8-01).

The photo depicts a bottlenose dolphin wearing a camera/instrument pack used for monitoring kinematic movements during deep dives. The small camera/instrument pack also contains a time-depth recorder and velocity meter. The camera is faced backwards in order to videotape the movements of the fluke during horizontal swimming and descent and ascent of dives. A neoprene belt and dorsal fin saddlepack was used to mount the instrumentation of free ranging dolphins at sea. Similar instrumentation was used for the other species examined in this study.

GLIDE PERFORMANCE IN DIVING MAMMALS



A representative deep dive is presented for the Weddell seal (A, maximum depth = 385 m), northern elephant seal (B, 333 m), bottlenose dolphin (C, 115 m), and blue whale (D, 84 m). Each curve represents dive depth in relation to time elapsed during the dive. Color of the line corresponds to stroking (black) and gliding (red) periods. Stroking periods include both continuous stroking and stroke-and-glide activities. Note the prolonged gliding period during descent for each species.



Percentage glide time during descent in relation to dive depth for four species of marine mammal. Each point represents an individual dive. The range of depths was determined by the free ranging behavior of the instrumented animals.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Office of Naval Research**
Project Identification Number:	**00PR05102**
Project Title:	**Coping with ischemia and reperfusion: Physiology of free radicals in diving birds and mammals**
Investigator(s):	**Zenteno-Savín , Tania**
Department or Division:	**N/A**
Performing Organization:	**Centro de Investigaciones Biológicas del Noroeste, S.C.**
Geographic Location of Study:	**Baja California Sur, Mexico**
Marine Mammal Species Involved:	**Ringed seal, Emperor penguins**
FY 00 Funding Level:	**27,324**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The specific mechanisms involved in protecting marine bird and mammal tissues from generation of free radicals and their deleterious effects are not known and are the subject of this research. The short-term objective of this study is to do a selective analysis of the antioxidant defenses which may endow marine birds and mammals with the tolerance to repeated cycles of ischemia/reperfusion associated to diving. To achieve this, the activities of the main antioxidants, rate of production of superoxide radical, and lipid peroxidation (as an index of free radical-induced damage) in extracts of tissues from ringed seal and emperor penguin will be determined. The long-term goal of this project is to study how marine birds and mammals detect and respond to hypoxia, ischemia/reperfusion and oxidative stress associated to diving.

We hypothesize that marine birds and mammals have a large antioxidant capacity in constant preparedness for coping with the potential oxidative stress induced by continuous cycles of breath-hold diving and the concomitant ischemia/reperfusion.

ANNUAL PROGRESS REPORT

Name: Zenteno-Savín

Grant Number: N00014-00-1-0314

Title: Coping with ischemia and reperfusion: Physiology of free radicals in diving birds and mammals

Award Period: February 2000 - February 2003

Objective:
The specific mechanisms involved in protecting marine bird and mammal tissues from generation of free radicals and their deleterious effects are not known and are the subject of this research. The short-term objective of this study is to do a selective analysis of the antioxidant defenses which may endow marine birds and mammals with the tolerance to repeated cycles of ischemia/reperfusion associated to diving. To achieve this, the activities of the main antioxidants, rate of production of superoxide radical, and lipid peroxidation (as an index of free radical-induced damage) in extracts of tissues from ringed seal and emperor penguin will be determined. The long-term goal of this project is to study how marine birds and mammals detect and respond to hypoxia, ischemia/reperfusion and oxidative stress associated to diving. We hypothesize that marine birds and mammals have a large antioxidant capacity in constant preparedness for coping with the potential oxidative stress induced by continuous cycles of breath-hold diving and the concomitant ischemia/reperfusion.

Approach:
Using colorimetric techniques, we will evaluate the rate of production of superoxide radicals, activity of a pro-oxidant enzyme, the activities of the mani antioxidant enzymes, concentrations of non-enzymatic free radical scavengers, as well as lipid peroxidation in extracts of tissues form ringed seals, Phoca hispida, and emperor penguins Aptenodytes forsteri. These determinations will be made under basal conditions and under stimulated oxidative stress.

Accomplishments:
Due to a delay in transferring the funds to the recipient institution, little action has been taken towards this projest. However, during April 2000, Dr Zenteno-Savín visited Dr. Paul Ponganis' laboratory at University of California San Diego-Scripps Institution of Oceanography to do some preliminary analyses on emperor penguin muscle biopsies. Baseline production of superoxide radical, lipid peroxidation, and total antioxidant status were obtained from 4 penguins; data is available for swimming (pectoral) and non-swimming (leg) muscles from these penguins. There appears to be a difference between swimming and non-swimming muscles; however, further analyses are needed in order to confirm this using statistical methodologies. During May and June 2000 we were able to analyze the production of superoxide radical, lipid peroxidation, and total antioxidant

status in samples from ringed seals that had been obtained the previous year. In addition, during July Dr Zenteno-Savín and Dr Robert Elsner, University of Alaska Fairbanks, went to Barrow, Alaska, to obtain fresh samples from ringed seals. Samples of heart, kidney and muscle were obtained from 7 seals; oxidative stress was simulated in these samples by incubating with xanthine/xanthine oxidase. All the samples, controls and replicates obtained were transported to Centro de Investigaciones Biológicas del Noroeste, S.C., La Paz, Baja California Sur, México, to be analyzed.

Significance:
This study is intended to be a selective and comparative analysis of free radical and antioxidant metabolism in tissues from marine organisms. Seals and penguins are well adapted to living in the ocean, and breath-hold diving is part of their every day routine. During many dives, blood flow redistribution is diverted from peripheral tissues towards the central nervous system (Dormer et al. 1977, Guppy et al. 1986). Even coronary blood flow may be considerably reduced and intermittent (Elsner et al. 1985). At the termination of a dive, blood flow is restored in all tissues and normal tissue function is preserved (Elsner and Gooden 1983). In contrast, organs of terrestrial mammals are highly susceptible to injury after occlusion of blood flow (Halasz et al. 1973). The sudden replenishment of oxygen and the resulting generation of oxygen-derived free radicals produced by reoxygenation of hypoxic tissues may induce morphologic disruption of membranes, interference with organelle and cell function, cell death and tissue necrosis. The specific mechanisms involved in protecting penguin and seal tissues from generation of free radicals and their deleterious effects are not known and are the subject of this research. This project seeks to understand the metabolic adaptations and physiologic mechanisms that allow marine birds and mammals to cope with the hypoxia, ischemia/reperfusion and oxidative stress associated to breath-hold diving, which would help us understand how this factors affect human divers and how to deal with specific pathologies associated with exposure to hypoxia, ischemia/reperfusion and oxidative stress. For example, oxygen toxicity, an important problem for human divers, is at the cellular level an effect of the free radicals; therefore, marine birds and mammals can be thought of as models for the stdy of such condition.

Work Plan:
It is anticipated that within the next year, Dr Ponganis will obtain more muscle biopsies from emperor penguins near McMurdo Station, Antarctica, through his NSF projects; as soon as these samples are available, Dr Zenteno-Savín will travel to San Diego to run the analyses. All ringed seal samples obtained from this season will be analyzed. An abstract with the preliminary results for production of superoxide radical and lipid peroxidation in heart, kidney and muscle from ringed seals has been submitted to The Oxygen Socitey meeting, to be held in San Diego, CA, next November.We are anticipating recruitment of another graduate student to help with analyses of the antioxidants in seal and penguin samples.

Publications, Abstracts, Technical Reports, Patents, and Awards :

Ellsworth, L.B., D.J. StAubin, J.L. Dunn & T. Zenteno-Savín. Effects of saline infusions on circulating levels of plasma atrial natriuretic peptide in harbor seals (*Phoca vitulina*). Submitted to Journal of Aquatic Mammals.

Zenteno-Savín, T., G. Ceballos & R. Rubio. Effects of AVP in heart are mediated by specific intravascular endothelial receptors. Submitted to European Journal of Pharmacology.

STRATEGIC ENVIRONMENTAL RESEARCH & DEVELOPMENT PROGRAM (SERDP)

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**SERDP**
Project Identification Number:	**CS-1082**
Project Title:	**Information and Technology Tools for Assessment and Prediction of Potential Impact of Military Noise on Marine Mammals**
Investigator(s):	**Helweg, David**
Department or Division:	**Code D3501E**
Performing Organization:	**SPAWARSYSCEN San Diego**
Geographic Location of Study:	**NPAC (baleen whales), NATL (Tursiops)**
Marine Mammal Species Involved:	**mysticetes; *Tursiops truncatus***
FY 00 Funding Level:	**397,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

SERDP Project CS-1082 is developing models and signal processing tools to help the DOD to understand the effects of underwater sound on marine mammals. The project consists of three thrusts, which link together to form a broad understanding of factors important in marine mammal sensitivity to various sound frequency-intensity combinations. The first thrust consists of detailed investigation of marine mammal auditory anatomy. The goal is to gain understanding of normal variation in marine mammal ear structures, including variables such as how the ears of dolphins change with age and gender (just as our human ears do). The second goal is to relate observed anatomical differences to hearing ability. By combining understanding of anatomy and hearing, predictions can be made as to (i) anatomical changes that are not normal; (ii) the structures most susceptible to damage from

underwater sound exposure; and (iii) estimation of auditory sensitivity from anatomical measurements. The second thrust combines expertise in marine mammal auditory anatomy with state-of-art computer techniques to produce computational models of baleen whale hearing. These computational models ("*WhalEar*" models) provide predictions of the relative sensitivity of each whale species to different sound types to which the whales may be exposed. Anatomical estimates of frequency sensitivity are integrated with comparative psychoacoustical information to predict a hearing sensitivity curve for each whale species. The SPAWAR High Performance Computer is used to derive an optimal filter configuration for each whale hearing curve using Evolutionary Programming algorithms. The *WhalEar* filter sets represent the hearing of a species of whale, and have been used to predict (i) sensitivity to many types of manmade underwater sound such as sonar and seismic exploration waveforms, and (ii) the potential masking of whale communication calls by such sounds. The third thrust – the "Smart Whale Acoustic Monitor" (*SWAM*) toolkit – provides an inexpensive signal processing system that detects whale calls, identifies the species, and estimates the location of the calling whale. When compiled over time, these data provide a summary of relative whale abundance, distribution, and movement. These data can assist allow the DOD to better plan activities that generate underwater sounds to help reduce the exposure of free-ranging whales to anthropogenic sound..

CS-1082 was awarded the SERDP Conservation Project of the Year in 2000. The project has yielded 8 publications and results have been reported at 5 conferences. The "SWAM" toolkit has been transitioned to the "M3P" Program at ONR.

NAVAIR
COMMAND

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **NAVAIR Command (PMA-248)**

Project Identification Number: **NAVAIR 1**

Project Title: **East Coast Shallow Water Training Range (ECSWTR) Marine Mammal Acoustic Impact Assessment (MMAIA)**

Investigator(s): **Jessica A. Ward, Code 74, Colin Lazauski, Code 74, Tom Fetherston, Code 551, Glenn Mitchell, Code 551**

Department or Division: **NAVSEA Newport, Code 74**

Performing Organization: **NAVSEA Newport, Code 74**

Geographic Location of Study: **N/A**

Marine Mammal Species Involved: **Various**

FY 00 Funding Level: **120,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

The purpose of this program is to quantitatively assess the potential for underwater acoustic emissions from Naval platforms associated with ECSWTR training operations to impact marine mammals. The effort utilizes an existing NUWC acoustic model coupled with custom MATLAB programs to assess impact based on various inputs including acoustic impact threshold, operational scenario and marine mammal density. This information will be incorporated into the ECSWTR Environmental Impact Statement.

CNO N45

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **CNO N45**

Project Identification Number: **CNO 1**

Project Title: LMRIS support services & applications of acoustic sensing to vessle-based marine mammal line transect surveys

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Investigator(s): **Barlow, Jay**

Department or Division: **N/A**

Performing Organization: **Southwest Fisheries Science Center**

Geographic Location of Study: **California Coast**

Marine Mammal Species Involved: **various**

FY 00 Funding Level: **150,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

This project supports the acoustic monitoring aspect of at-sea surveys and the development of the algorithms to generate density plots from the line transect data in LMRIS.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CNO N45**
Project Identification Number:	**00PR03921**
Project Title:	**Baleen Whale Calls and Seasonal Ocean Ambient Noise**
Investigator(s):	**Hildebrand, John**
Department or Division:	**Applied Physics Lab**
Performing Organization:	**Scripps Institution of Oceanography**
Geographic Location of Study:	**San Diego, CA**
Marine Mammal Species Involved:	**Blue and Fin whales (acoustics only)**
FY 00 Funding Level:	**49,993**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective is to determine the statistics and sources of low-frequency ambient sound in the ocean. Spectral data collected off SOSUS is used to estimate the seasonal acoustic population density for several types of whale species and call types. An initial analysis of data for only basic call types of blue and fin whales has shown whales to be a significant contributor to ambient noise in the 15-22 Hz band; this study shows an even greater contribution to ocean noise from whales.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **CNO N45**

Project Identification Number: **00PR04774**

Project Title: Anatomical Investigations of Auditory Structures of Beaked Whales

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Investigator(s): **Ketten, Darlene**

Department or Division: **Biology**

Performing Organization: **Woods Hole Oceanographic Institute**

Geographic Location of Study: **Puerto Rico**

Marine Mammal Species Involved: **Beaked whale**

FY 00 Funding Level: **6,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

To examine the temporal bones and heads of beaked whales stranded in Puerto Rican and nearby Caribbean waters between October, 1999 and May, 2000 in order to determine whether strandings associated with naval activity have a higher or correlated incidence of auditory pathology.

ANNUAL PROGRESS REPORT

Name: Ketten

Grant Number: N000140010284

Title: Anatomical Investigations of Auditory Structures of Beaked Whales

Award Period: 01/15/2000 - 05/31/2000 (6 months)

Objective:
To examine the temporal bones and heads of beaked whales stranded in Puerto Rican and nearby Caribbean waters between October, 1999 and May, 2000 in order to determine whether strandings associated with naval activity have a higher or correlated incidence of auditory pathology.

Approach:
Direct examination, CT scanning when feasible, and gross dissection were used to document and assess the state of the ears and related head structures of stranded beaked whales. If the preservation state warranted further investigation, the inner ears of the animals were extracted for histologic processing.

Accomplishments:
Under the directly funded effort, the PI traveled to Puerto Rico at the request of several Naval sectors to examine the remains of beaked whales (*Ziphius cavirostris* and *Mesoplodon spp.*) that stranded in the Virgin Islands and Puerto Rico within the last year. Heads from these strandings were collected by Dr. Antonio Mignucci and, with the exception of one head, were flensed and buried prior to the examination. Consequently, for the majority of speciments, only bony elements were available to assess. All appeared to be normal adult male or female skulls with unremarkable pathology with the exception of one skull which had an aberrant rigt jaw with evidence of healed fractures (>3 years post injury bone remodeling) and attendant osteolytic areas. The audtory bulla on this side showed parallel otosclerotic changes, with rugose surfaces overall.

Significance:
The residual bony elements of the ears in the majority of animals examined are consistent with normal hearing. The male with an abnormal jaw and ear is assumed to have had moderate to profound hearing loss as labyrintitis ossificans is an expected outcome from a fulminating infection involving the ear region. The jaw was extensively ravaged and the patterning suggests repeat and severe infectious bouts. In most mammals, sympathetic loss is common in the contralateral ear, therefore this animal is likely to have had a long term, infection derived bilateral hearing impairment. There was no evidence in any of the skulls of trauma consistent with recent loss.

Work Plan:
The grant and related work are completed. The results will contribute to other grants related to beaked whale morphometry.

Publications, Abstracts, Technical Reports, Patents & Awards:
The only publication at this time is an in-house ONR/N45 summary report of the findings distributed as email to the relevant program directors. Briefings were also provided to Adm. Gaffney, Adm. West, Dr. V. F. Stone, Cdr. Stamey, and Secty. Pirie.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CNO N45**
Project Identification Number:	**00PR07201**
Project Title:	**Experimental measures of blast trauma in Marine Mammals**
Investigator(s):	**Ketten, Darlene**
Department or Division:	**Biology**
Performing Organization:	**Woods Hole Oceanographic Institute**
Geographic Location of Study:	**Woods Hole Oceanographic Institute**
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**157,008**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The explicit objective is to determine the dynamic range of mechanical responses of marine mammal ears re: intense impulse sources. Ears are the bell-weathers of pressure induced damage. Equally important, they are a crucial sensory system for marine mammals. Understanding impacts on marine mammal ears from blast pressures will provide a marine specific metric for determining blast and impulse exposure safety zones.

ANNUAL PROGRESS REPORT

Name: Ketten

Grant Number: N00014-97-1-1030

Title: Experimental measures of blast trauma in Marine Mammals

Award Period: 01 September 1997 – 30 September 2001

Objective:
The explicit objective is to determine the dynamic range of mechanical responses of marine mammal ears re: intense impulse sources. Ears are the bell-weathers of pressure induced damage. Equally important, they are a crucial sensory system for marine mammals. Understanding impacts on marine mammal ears from blast pressures will provide a marine specific metric for determining blast and impulse exposure safety zones.

Approach:
Cetacean and land mammal ears differ in their robustness, stiffness, mass, vascularization, and pneumatization characteristics. It is not possible to accurately extrapolate marine auditory system responses from existing experimental results on air-adapted ears without a better understanding of any in their pressure and mechanical responses. These experiments are designed to provide direct measures from marine auditory systems of intense pressure responses. Although responses in live animal would give the most accurate measures of damage and recoverability from blast exposures, they are not feasible for most marine mammals. However, post-mortem ears, given proper handling, have mechanical responses isomorphic with live ears. Because auditory system trauma from blasts depends upon mechanical responses of ear components, some of these effects are inducible and measurable post-mortem. In this project, carcasses of stranded marine mammals are examined post-mortem by CT to assure normal ear structures. The ears and post-cranial organs are then implanted with pressure gages. The implanted, intact specimen is immersed in a test pond, exposed to a single blast, re-examined by CT to document gross changes, and fully necropsied to assess internal damage at the cellular and infrastructural level. All scans, exposures, and necropsies are video or still photo documented.

Accomplishments:
The following experiments have been completed since the grant's activation in Jan. 1999: 1) Four preliminary test pond mapping shots were performed to test the resilience of the specimen suspension system and to confirm received pressure model simulations for expected specimen placements within the test pond. 2) Two specimen simulation tests utilizing gages implanted in hams and two simulated cetacean ear tests were performed to confirm *in situ* gage integrity when implanted in soft tissues, in flexible air cavities, and at bone-soft tissue interfaces. For the latter tests, four pseudo-cetacean ears were constructed of acrylic shells equivalent to the volumes of small delphinid and larger

baleen ears. Each shell was filled with varying combinations of flexible or semi-rigid walled air-cavities (balloon catheters or acrylic chambers), hydrated soft tissue only, and air only chambers. 3) Six actual tests of porpoise and dolphin post-mortem specimens have been conducted with gages implanted in the ear, esophagous, and hypaxial musculature. The specimens were tested at 300 psi (1 animal), 200 psi (1), 100 psi (2) , 50 psi (1) , and 25 psi (1) received pressure at the animal's surface. High received pressures were purposely chosen for the initial tests to test the feasibility of the measures and to determine how well the gages would respond in actual tissues.
The results of the blast tests to date are as follows:

(1) Tests without target specimens confirmed pressure simulations are correct for pressures down to 25 psi and showed that the suspension rigging would withstand the test pressures anticipated without compromising received psi measurements.
(2) Simulated ear and tissue tests provided data for improvements in gage design and acted as trials for video equipment placement. These preliminary tests were required because the rarity and delicacy of appropriate postmortem specimens requires optimizing all recording equipment parameters prior to actual tests.
(3) Actual specimen test data are still considered preliminary but are encouraging. As a control, all specimen necropsies are performed and documented by AFIP-trained forensic and blast pathologists who are not privy to the received levels. Necropsy findings for the specimens examined to date show distinct and unequivocal damage consistent with - and only with - blast effects. The injuries sustained by all specimens at high psi (e.g., peri-bullar, intra-cochlear, and intracranial hemorrhage, subluxated ossicles, lung and liver disruption and hemorrhage) were profound and likely mortal, but, interestingly, the severity and number of impacts clearly decreases with psi and was consistent with mass-dependent predictions from previous studies on land mammals.

In summary, the test pond has been fully mapped; all apparatus tests were completed; and five full specimen tests have been completed. The specimen tests show graded damage that is inversely related to specimen mass. Suites of damage (number of organs involved, severity, etc) are consistent with received pressure and orientation of the specimens. In addition, some organs, including blubber, jaw fats, and melons, that are unique to cetaceans are differentially impacted based on received psi and may serve as diagnostic correlates for blast injuries. We expect that not only will these experiments provide conservative estimates of auditory trauma, but also that the data may provide a basis for calculating continual dose-damage curves for multiple marine species.

Significance:
The Navy is required to mitigate effects on marine mammals from blasts required for ship shock trials as well as other explosive and impulse sources. Currently, mitigation zones are being set by inference from land mammal experiments because we lack explicit data on pressure effects in marine mammals. As noted above, ears are vital sensory organs that are also primary indicators for pressure damage. By directly measuring and monitoring pressure damage in marine mammals and finding the endpoints for pressure-induced trauma, this project will provide the navy with the necessary baseline data for accurate aquatic mitigation zones. The current, preliminary data from the six

experiments completed show that similar trauma mechanisms occur in marine and land mammal abdominal tissues. The ear, associated jaw fats, melon, and blubber display marine mammal specific trauma suites that are directly correlated with internal received pressures and may be used diagnostically in strandings suspected to have impulse trauma. The data also show that like land mammals, there is a clear mass dependence effect in the severity of trauma incurred.

Work Plan:
A minimum of 4 and a maximum of 10 additional cetacean specimens are expected to be tested under current funding. These will range from 50 to 120 kg. cetaceans with replicate pressure exposures at 300, 200, 100, 50, 25, 10, and 0 psi, as required, to determine zones (based on received psi) of lethality, recoverable injury, permanent, temporary, and no significant structural auditory damage.

Publications, Abstracts, Technical Reports, Patents & Awards:
Supported Publications:

Ketten, D.R. (1997) Structure and Function in Whale Ears, *Bioacoustics*, vol. 8, no. 1, pp. 103-136.

André, M., C. Kamminga, and D. Ketten (1997) Are Low Frequency Sounds a Marine Hearing Hazard: A Case Study in the Canary Islands. *Proc. of the Inst. of Acoustics*, vol. 19, no. 9, pp. 35-43.

Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. *Proc. Int. Cong. on Acoust.*, vol. 3, pp. 1657-1660.

Ketten, D.R., Skinner, M., Wang, G., Vannier, M., Gates, and Neely, G. (1998) *In vivo* Measures of Cochlear Length and Insertion Depths of Nucleus® Cochlear Implant Electrode Arrays. *Annals of Otology and Laryngology*, vol. 107, no. 11, pp. 1-16.

de Muizon, C., D.P. Domning, and D.R. Ketten (1999) *Odobenocetops peruvianus*, the walrus-convergent delphinoid from the lower Pliocene of Peru (in press, *Smithsonian Cont. Paleobiol.*).

Brill, R.L., P.W.B. Moore, L.A. Dankiewicz, and D.R. Ketten (2000) Pan bone thresholds and evidence of hearing loss in an Atlantic bottlenose dolphin (Tursiops truncatus) (submitted, *JASA*)

Nadol, J.B., Jr., J.Y. Shiao, B. Burgess, D.R. Ketten, D.K. Eddington, B.J. Gantz, I. Kos, P. Montandon, N.J. Coker, J.T. Roland, Jr., and J.K. Shallop (2000) Histopathology of Cochlear Implants. *Annals of Otology and Laryngology* (in press).

Ketten, D.R. (1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. In: Report of the Bioacoustics Panel, NATO/SACLANT, A. D'Amico and W. Verboom (eds.), pp. 2/21, 2/63-78.

Ketten, D.R. (1998) Marine Mammal Auditory Systems: A Summary of Audiometric and Anatomical Data and Its Implications for Underwater Acoustic Impacts. NOAA Tech. Memor. NMFS, NOAA-TM-NMFS-SWFSC-256, 74 pp

Popper, A., Ketten, D.R., Dooling, R., Yost, W., Brill, R., Ridgway, S., and Shusterman, R. (1999) Effects of Anthropogenic Sounds on Hearing in Marine Animals. ONR Tech. Rpt., pp. 52-89.

Wartzok, D. and D.R. Ketten (1999) Sensory Biology. In: *Marine Mammals*. J. Twiss and J. Reynolds (eds.), Vol. 1, Smithsonian Institution Press, pp. 117-175.

Ketten, D.R. (2000) Cetacean Ears. In: *Hearing by Whales and Dolphins*. W. Au, R. Fay, and A. Popper (eds.), SHAR Series for Auditory research, Springer-Verlag, pp. 43-108.

Published Abstracts/Invited lectures:

Ketten, D.R. (1997) Marine Mammal Hearing: How do they do it and What are we doing to it. *Invited paper*, 1997 Northeast Regional Stranding Network Conference.

André, M., C. Kamminga, and D. Ketten (1997) Are Low Frequency Sounds a Marine Hearing Hazard: A Case Study in the Canary Islands. Underwater Bio-Sonar and Bioacoustics Symposium, Loughborough University, England.

Brill, R.L., P. W. B. Moore, L. A. Dankiewicz, and D.R. Ketten (1997) Evidence of hearing loss in an Atlantic bottlenose dolphin (*Tursiops truncatus*). *Invited paper*, 134th Meeting, Acoustical Society of America.

Ketten, D.R., P. W. B. Moore, L. A. Dankiewicz, and W. Van Bonn (1997) The slippery slope of a Johnsonian ear: Natural variability versus natural loss. *Invited paper*, 134th Meeting, Acoustical Society of America.

Ketten, D.R., Dolphin, W.F., Chittick, E.J., Krum, H.N., and Merigo, C. (1998) *In vivo* imaging correlated with otoacoustic emissions as a metric for ear disease in seals, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.

Ketten, D.R. (1998) Man-made noise in the oceans: Irrelevant or irreparable? *Plenary lecture*, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.

Ketten, D.R. (1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. *Invited lecture*, Bioacoustics Session. NATO/SACLANT Mtg. on LFS Effects, La Spezia, Italy.

Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. *Plenary Lecture*, joint meeting, International Congress on Acoustics/Acoustical Society of America.

Ketten, D.R. (1998) Acoustic/Explosive Effects on Marine Mammals, *Invited lecture*, 1998 Information Transfer Meeting, Minerals Management Service.

Ketten, D.R. (1999) Whale Ears and Anatomy: How to See What They Hear. US NE Student Chapter for Marine Mammalogy. *Invited lecture*, WHOI.

Ketten, D.R., H. Krum, E. Chittick, C. Merigo, and E. Melvin (1999) Acoustic Fatheads: Parallel Evolution of Soft Tissue Conduction Mechanisms in Marine Mammals, Turtles, and Birds, *Invited paper. joint* meeting, Acoustical Society of America/ European Acoustics Association, Berlin.

Ketten, D.R. and J. R. Potter (1999) Anthropogenic ocean noise: Can we quantify the impact? joint meeting, Acoustical Society of America/European Acoustics Association.

Ketten, D.R. (1999) Water, Fat, and Acoustic Impedance Matching: Soft Tissues Adaptations for Underwater Hearing in Turtles, Seabirds, and Marine Mammals. 1st International Conference on Sensory Processing of the Aquatic Environment, Great Barrier Reef, Australia.

Ketten, D.R. (1999) Ear damage in whales, *Invited lecture,* Marine Mammal Bioacoustics Short Course, Acoustical Society of America and Society for Marine Mammalogy.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CNO N45**
Project Identification Number:	**00PR07888**
Project Title:	**SWFSC Marine Mammal Abundance Data for Input into LMRIS**
Investigator(s):	**Mullin, Michael**
Department or Division:	**N/A**
Performing Organization:	**University of California, San Diego**
Geographic Location of Study:	**San Diego, CA**
Marine Mammal Species Involved:	**various**
FY 00 Funding Level:	**50,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The objective is to apply state-of-the-art modeling techniques to convert line transect point sighting data into variable scale density estimators that take into account the environmental correlates of animal density and movement patterns.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CNO N45**
Project Identification Number:	**00PR07614**
Project Title:	**Whale Signature Analysis from IUSS Data**
Investigator(s):	**Watkins, William**
Department or Division:	**Biology**
Performing Organization:	**Woods Hole Oceanographic Institution**
Geographic Location of Study:	**North Pacific Ocean**
Marine Mammal Species Involved:	**Blue, Fin and Humpback whales**
FY 00 Funding Level:	**250,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Continuation of a long-term monitoring study begun in 1994 under SERDP sponsorship. Navy SOSUS underwater listening arrays capable of monitoring much of the north Pacific Ocean are used to sample for calls from blue, fin, humpback and other large whale species. Monthly summaries of signal detections and localizations are plotted and relative seasonal densities, movements of these species are determined from the continuous acoustic record.

CINCLANTFLT

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Commander in Chief, Atlantic Fleet (CINCLANTFLT)**
Project Identification Number:	**00060CLF10**
Project Title:	**Charleston and Jacksonville Operating Area Marine Resources Assessment**
Investigator(s):	**Higginson, Deanna**
Department or Division:	**Atlantic Division, Naval Facilities Engineering Command (LANTDIV)**
Performing Organization:	**Geo-Marine, Inc.**
Geographic Location of Study:	**Off shore waters of Charleston, SC and Jacksonville, FL**
Marine Mammal Species Involved:	**Various Cetaceans and Manatee**
FY 00 Funding Level:	**340,353**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Final report expected in March 2002, this is a literature search and compilation where the final report will indicate temporal and spatial distribution of marine mammals in the Charleston and Jacksonville OPAREAs.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Commander in Chief, Atlantic Fleet (CINCLANTFLT)**
Project Identification Number:	**00389M0081**
Project Title:	**Manatee Aerial Survey**
Investigator(s):	**Higginson, Deanna**
Department or Division:	**Atlantic Division, Naval Facilities Engineering Command (LANTDIV)**
Performing Organization:	**Geo-Marine, Inc.**
Geographic Location of Study:	**Vieques Island, Puerto Rico**
Marine Mammal Species Involved:	**Manatee and Various Cetaceans**
FY 00 Funding Level:	**64,198.70**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

The primary purpose of this project is to conduct aerial surveys for manatees and to take note of other marine mammals and sea turtles in the waters surrounding the Island of Vieques. Marine mammal and threatened and endangered species distribution data are important to the Navy in planning exercises or other activities to avoid any impact to protected species. The purpose of this survey effort is to obtain sufficient data to determine presence or absence of marine mammals (particularly manatee) and sea turtles around Vieques Island and particularly the Live Impact Area (LIA). The contractor shall conduct at a minimum, 23 full day surveys. Surveys shall occur once a week throughout the specified time period (weather permitting). Each full day of surveying will consist of a minimum of 1.5 hours in the morning (after sunrise), 1.5 hours in the afternoon, and 1.5 hours before sunset.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Commander in Chief, Atlantic Fleet (CINCLANTFLT)**
Project Identification Number:	**00060CLF10**
Project Title:	**St. Croix Underwater Tracking Range (UTR) and Puerto Rico Operating Area Marine Resources Assessment**
Investigator(s):	**Higginson, Deanna**
Department or Division:	**Atlantic Division, Naval Facilities Engineering Command (LANTDIV)**
Performing Organization:	**Geo-Marine, Inc.**
Geographic Location of Study:	**St. Croix, Offshore Waters North and South of Puerto Rico**
Marine Mammal Species Involved:	**Various Cetaceans and Manatee**
FY 00 Funding Level:	**396,367**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Final report expected in March 2002, this is a literature search and compilation where the final report will indicate temporal and spatial distribution of marine mammals in the St. Croix UTR and Puerto Rico OPAREA.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Commander in Chief, Atlantic Fleet (CINCLANTFLT)**
Project Identification Number:	**00389M0082**
Project Title:	**Vieques Exercise Aerial Surveys (mitigation)**
Investigator(s):	**Higginson, Deanna**
Department or Division:	**Atlantic Division, Naval Facilities Engineering Command (LANTDIV)**
Performing Organization:	**Geo-Marine, Inc. Fajardo, Puerto Rico**
Geographic Location of Study:	**Waters surrounding Vieques Island, Puerto Rico**
Marine Mammal Species Involved:	**Various cetaceans and West Indian manatee**
FY 00 Funding Level:	**400,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

Information from these aerial surveys is gathered prior to, during, and after Navy Operations as part of agreements with NMFS and USFSW to determine if the area to be used for Naval Operations is clear of marine mammals. This information is also complied to help plan activities so that marine mammals can be avoided in operational planning. Information is also being analyzed to determine seasonality and habitat use of the area surrounding Vieques Island for future exercise planning. Work is ongoing, summary reports are available at any time.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**Commander in Chief, Atlantic Fleet (CINCLANTFLT)**
Project Identification Number:	**00060CLF10**
Project Title:	**Virginia Capes Operating Area Marine Resources Assessment**
Investigator(s):	**Higginson, Deanna**
Department or Division:	**Atlantic Division, Naval Facilities Engineering Command (LANTDIV)**
Performing Organization:	**Geo-Marine, Inc.**
Geographic Location of Study:	**Virginia Capes (Mid-Atlantic)**
Marine Mammal Species Involved:	**Various Cetaceans**
FY 00 Funding Level:	**493,397**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *et*c.)

Final report expected in August 2001, this is a literature search and compilation where the final report will indicate temporal and spatial distribution of marine mammals in the VACAPES OPAREA.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CINCLANTFLT**
Project Identification Number:	**CINCLANT 1**
Project Title:	**OPAREA Habitat Assessment**
Investigator(s):	**Mitchell / Fetherston / Kenney / Phelps**
Department or Division:	**NAVSEA Newport, Code 551**
Performing Organization:	**NAVSEA Newport, Code 551**
Geographic Location of Study:	**Northwestern Atlantic Ocean**
Marine Mammal Species Involved:	**northern right whale, humpback whale, fin whale, minke whale, sperm whale, bottlenose dolphin, white sided dolphin, white-beaked dolphin, common dolphin, long-finned pilot whale, Risso's dolphin, harbor seal, gray seal, harp seal, hooded seal**
FY 00 Funding Level:	**60,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

Work with Dr. R. Kenney and GEOMARINE Inc to provide evaluations of CINCLANT OPAREAS from a biological resource perspective. The initial task will focus on VACAPES.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CINCLANT**
Project Identification Number:	**CINCLANT 2**
Project Title:	**SINKEX Biological Assessment**
Investigator(s):	**Mitchell / Vars / Tompsett / Ward / Kenney**
Department or Division:	**NAVSEA Newport, Code 551**
Performing Organization:	**NAVSEA Newport, Code 551**
Geographic Location of Study:	**Puerto Rican Op Area, VACAPES**
Marine Mammal Species Involved:	**spinner dolphin, bottlenose dolphin, short finned pilot whale, common dolphin, pygmy sperm whale, sperm whale, Cuvier's beaked whale, humpback whale**
FY 00 Funding Level:	**50,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

Research and write biological assessment for use in formal Section 7 consultation. Report provided to CINCLANT. Coordinate and conduct Section 7 consultation with NMFS.

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**CINCLANTFLT**
Project Identification Number:	**CINCLANT 3**
Project Title:	**New Providence Channel Marine Mammal Stranding Investigation**
Investigator(s):	**O'Connor, Fetherston, Mitchell, Ward, Lazauski**
Department or Division:	**NAVSEA Newport, Code 312**
Performing Organization:	**NAVSEA Newport, Code 312**
Geographic Location of Study:	**New Providence Channel**
Marine Mammal Species Involved:	**Beaked Whales**
FY 00 Funding Level:	**60,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

Use current modeling and analysis products to evaluate the sound field during the chokepoint transit training operation in March 2000, to aid in the joint NOAA NMFS/Navy investigation into possible relationships between Navy tactical sonars and observed mammal strandings in the New Providence Channel.

CINCPACFLT

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **CINCPACFLT**

Project Identification Number: **CINCPAC 1**

Project Title: **West Coast Shallow Water Training Range (WCSWTR) Marine Mammal Acoustic Impact Assessment (MMAIA)**

Investigator(s): **Ward, Fetherston, Lazauski, Mitchell, Jette**

Department or Division: **NAVSEA Newport, Code 74**

Performing Organization: **NAVSEA Newport, Code 74**

Geographic Location of Study: **San Clemente Island**

Marine Mammal Species Involved: **Various**

FY 00 Funding Level: **New**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The purpose of this program is to quantitatively assess the potential for underwater acoustic emissions from Naval platforms associated with San Clemente Island USW training operations to impact marine mammals. The effort utilizes an existing NUWC acoustic model coupled with custom MATLAB programs to assess impact based on various inputs including acoustic impact threshold, operational scenario and marine mammal density. This information will be incorporated into the San Clemente Island Environmental Impact Statement.

PMS 400

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency):	**PMS 400**
Project Identification Number:	**PMS 1**
Project Title:	**Gulf of Maine Biological Assessment**
Investigator(s):	**Fetherston / Mitchell / Kenney**
Department or Division:	**NAVSEA Newport, Code 551**
Performing Organization:	**NAVSEA Newport, Code 551**
Geographic Location of Study:	**Gulf of Maine**

Marine Mammal Species Involved: **Northern right whale, humpback whale, fin whale, minke whale, sperm whale, sei whale, bottlenose dolphin, white sided dolphin, white-beaked dolphin, common dolphin, long-finned pilot whale, harbor porpoise, Risso's dolphin, harbor seal, gray seal, harp seal, hooded seal**

FY 00 Funding Level: **New**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

Develop biological assessment for the Gulf of Maine to enable PMS 400 to evaluate sea trials conducted in support of the DDG 51 program. The effort will commence in FY 01.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **Naval Submarine Medical Research Laboratory**

Project Identification Number: **NSMRL 1**

Project Title: **Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA)--Low Frequency Sound Scientific Research Program (LFS SRP)**

Investigator(s): **Dr. Christopher W. Clark (Director, Bioacoustics Research Program at the Cornell University Laboratory of Ornithology), Dr. Peter Tyack (Associate Scientist at Woods Hole Oceanographic Institution [WHOI])**

Department or Division: **Cornell Laboratory of Ornithology; WHOI**

Performing Organization: **Cornell Laboratory of Ornithology; WHOI**

Geographic Location of Study: Continued ongoing analysis in FY 2000 of underwater acoustic and marine mammal behavioral data collected in the Southern California Bight, off the central California coast, and off the Big Island of Hawaii.

Marine Mammal Species Involved: **blue, fin, gray and humpback whales.**

FY 00 Funding Level: **260,880**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, etc.)

The Low Frequency Sound Scientific Research Program (LFS SRP), under the CNO (N774) task for development of the SURTASS LFA Sonar Environmental Impact Statement was designed to supplement the limited scope of data from previous studies on the impact of low frequency sound on baleen whales. This field

research program was based on a systematic process for selecting the marine mammal indicator species and field study sites, using inputs from several workshops involving a broad group of interested parties (academic scientists, federal regulators, and representatives of environmental and animal welfare groups).

The LFS SRP produced new information about responses to LF sounds at received levels from 120 to 155 dB. Controlled experimental tests were performed in three phases, involving the following species and settings:

- **Phase I: Blue and fin whales feeding in the Southern California Bight (September – October 1997);**
- **Phase II: Gray whales migrating past the central California coast (January 1998); and**
- **Phase III: Humpback whales off Hawaii (February – March 1998).**

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY DARPA

PROJECT SUMMARY
OF RESEARCH DIRECTLY OR INDIRECTLY RELATED TO
MARINE MAMMALS – FY 00

Supporting Organization (Agency): **DARPA**

Project Identification Number: **DARPA01**

Project Title: **Hardware Implementation and Evaluation of Dolphin Based Mine Hunting Principals**

Investigator(s): **Moore, Patrick & David A. Helweg**

Department or Division: **Biosciences Division D35**

Performing Organization: **SPAWAR SYSCEN, San Diego**

Geographic Location of Study: **San Diego, CA**

Marine Mammal Species Involved: **Tursiops truncatus**

FY 00 Funding Level: **619,000**

Project Summary: (Provide a brief summary that includes the aim of the study and anticipated outputs, i.e., primary publications, reports, *etc*.)

The project has two main objectives: (1) to design, fabricate, test, and evaluate a prototype dolphin-based sonar (DBS) and, (2) to use the DBS as a test platform to evaluate various biomimetic signal-processing strategies. The first objective is being pursued in cooperation with Applied Research Laboratory, University of Texas at Austin (ARL) using a Cooperative Research Agreement (CA). Under the CA ARL and SSC-SD have designed and are building the wet-end of the DBS. SSC-SD is building the dry-end: the topside control and signal processing unit and the instrument shelter required to take the system to sea for testing in the SW/VSW mine fields. In addition, the project leverages off a parallel Office of Naval Research project to redesign and upgrade an existing dynamic biosonar measurement tool (BMT) that collects data concerning the active minehunting behavior of a free-swimming dolphin in the open ocean. The tool will collect emitted

clicks; click train timing information, dynamic swimming motion, and the acoustic data stream in which returning echoes of targets are embedded. These data will form the basis for a bio-inspired signal processing strategy to be incorporated and evaluated in the DBS.